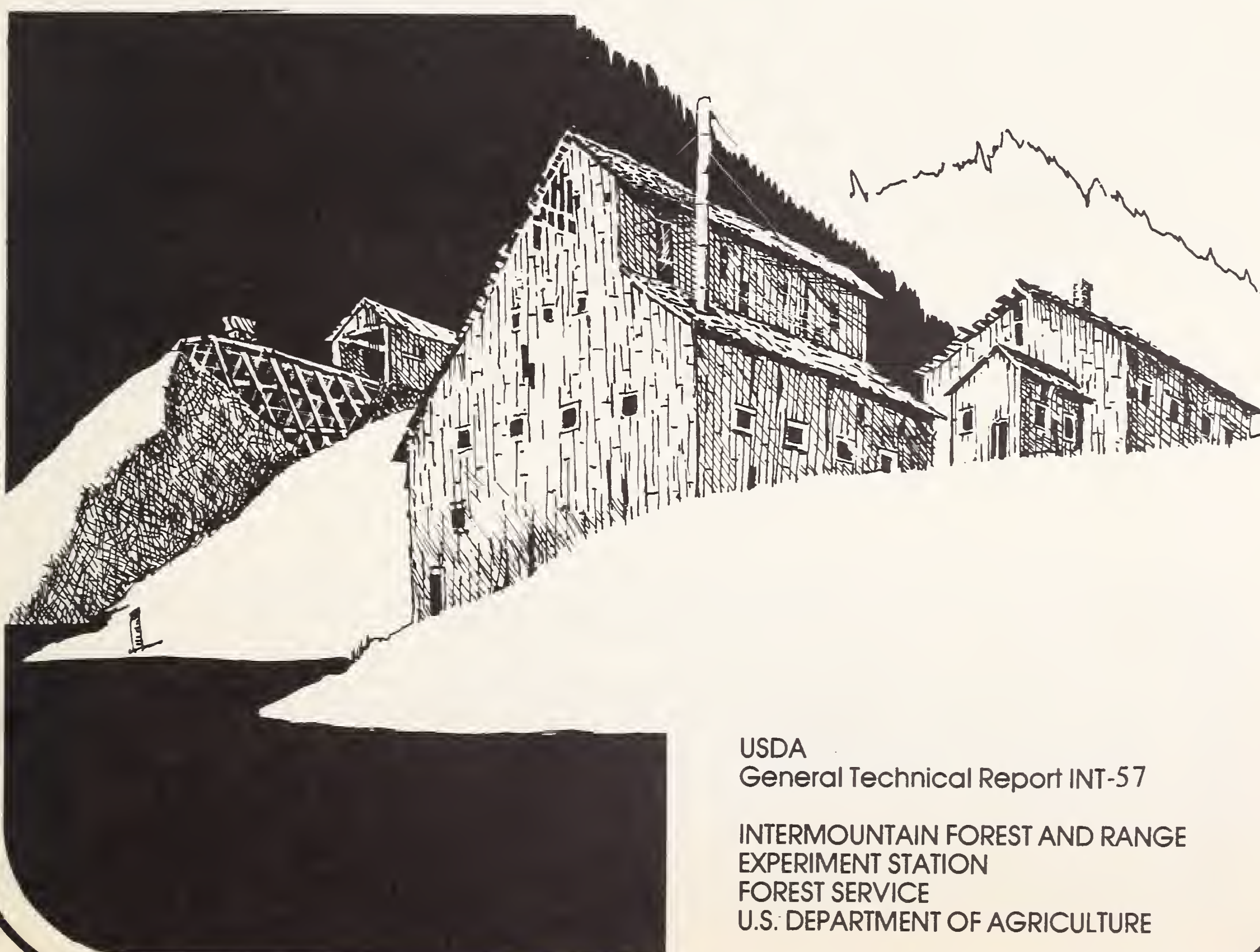
SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

A GUIDE TO RECLAIMING SMALL TAILINGS PONDS AND DUMPS



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A GUIDE TO RECLAIMING SMALL TAILINGS PONDS AND DUMPS

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RESEARCH SUMMARY

This report presents a sequential approach to reclaiming small tailings ponds and dumps in the Western United States. The report is based on a SEAM-funded project on the Sheldon Mine, an abandoned copper operation near Prescott, Ariz. The information herein is intended to aid land managers and reclamation specialists in planning and implementing reclamation of small tailings ponds and dumps.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Chapter One

INTRODUCTION

According to a 1966 estimate by the U.S. Bureau of Mines, more than 16,000 inactive and/or abandoned underground mines are scattered throughout the Western United States. More recent estimates have suggested that this list is incomplete and that the actual count may be more than twice as high. For instance, Colorado, alone, has more than 10,000 abandoned prospect sites. Many of these sites create continuing environmental damage in the forms of acid drainage into streams, lakes, and underground water supplies; production of sediment that shortens the life of lakes and ponds; and, visual disruption of scenic landscapes. Further, those abandoned mines that are still open to the surface pose a potential danger to anyone who would explore them.

In recent years, Federal and State agencies have been increasingly interested in the reclamation of these orphaned mines. However, historically this interest is a new phenomenon. Therefore, relatively little is written on the subject. This guide attempts to partially fill this void through discussion of problems and practices that may be encountered in the reclamation of abandoned underground mines. The approach taken is largely a qualitative one because, as yet, there are few hard rules and facts that specifically apply to such projects.

When first considered, the prospect of undertaking the reclamation of a small mine site may appear to be deceptively simple. In truth, such tasks can become highly complex. What may initially appear to be a simple matter of regrading and planting, occasionally can have the potential for generating a tangle of ecological, legal, and/or political problems. In addition, it is possible that the selected treatment simply may not be adequate to correct the conditions that exist at a given site. Accordingly, this book has been designed to lead planners, land managers, and contractors through various technical, environmental, economic, soical, and political aspects of planning the reclamation of orphaned mine sites by providing a basic background for the kinds of problems and situations that may be encountered. It is not designed to replace technical or legal consultants, whose services can often be invaluable in various phases of a project.

Because abandoned mines involve extremely diverse circumstances, the scope of this guide is as broad as possible. Its primary intention is to raise questions and discuss relationships, rather than to provide specific answers to problems that can only be determined individually for each project site. Some chapters are included to assist in the analysis of problems and gathering of data, while others assist with the actual planning of the reclamation operations and post-project maintenance and monitoring. The author assumes that a cost-benefit analysis has been completed before commencement of the serious project planning; therefore, this topic is not considered.

For the convenience of the reader, a question and answer format is used in portions of this book. Questions and points of wide applicability are raised, then discussed in general terms. However, certain items are not discussed further, because it is felt that their mention, alone, would be sufficient to initiate consideration by the reader. Also, it should be emphasized that many of the questions raised have no single or simple "correct" answers. Each situation encountered in the planning of a reclamation project must be dealt with in the context of those conditions unique to a particular mine site.

In addition, technical terminology is kept to a minimum. Many of the terms that are used are defined in the text, while others are included in the glossary in the appendix.

This handbook was conceived in connection with the reclamation of the Sheldon Mine tailings pond and waste dump at Lynx Creek, located near Prescott, Arizona. The project was a joint effort by Surface Environment And Mining (SEAM), the Prescott National Forest, and the University of Arizona. Because of the difficulties

encountered during the reclamation of the Sheldon Mine site, it was decided that there was a need for a project planning handbook. These experiences are used to illustrate various points in this guide. For this reason, brief summaries of the history of the mine, the ecological problems it generated, and its reclamation are included. Although this guide is partially based upon a specific project, it is hoped that it will prove to be generally applicable to a wide range of abandoned mine sites located throughout the Western United States.

The Lynx Creek Experience:

An Account of a Pilot Reclamation Project

Probably, the history of the Sheldon Mine is typical. It is briefly reviewed here to illustrate the evolution of a mine site over several generations of operation. Mining and processing techniques change with passing time, as do the economic conditions that ultimately control the development of a mine and the possibility of reworking its tailings. As discussed later, the operational history of a mine directly affects the structure and content of its waste dumps and tailings ponds.

THE SHELDON MINE

The Sheldon Mine is located within the Lynx Creek watershed in the Prescott National Forest, approximately 12.8 km (8 miles) southeast of Prescott, Arizona. This area had been the site of considerable gold and silver mining activity, which sporadically continued for nearly a century following the discovery of gold in 1863. In addition to numerous underground mines, Lynx Creek itself was placer mined from the late 1880's until World War II.

The town of Walker, Arizona, grew up in the midst of numerous mining claims along Lynx Creek. In 1863, Captain Joseph Walker, led a mining expedition into the Hassayampa Creek area of the Arizona Territory. Their prospecting activities eventually led to the adjacent Lynx Creek watershed, where they found veins of gold, copper, silver, and lead. With the establishment of the town of Walker as the first Anglo-Saxon community in northern Arizona, the population grew until it reached its peak of 3,000. For a while this was the largest settlement in Arizona. The town experienced several population fluctuations that paralleled mining activities in the watershed. In the 1930's, it rapidly declined. Then, after a brief flurry of mining during the early part of World War II, it gradually disintegrated. Today, there are several active mining claims and summer cabins in the district, along with some permanent residents.

Gold was found at the site of the Sheldon Mine in December, 1882. Almost 17 years later, in 1899, a patent was filed. The deposit was periodically worked under various owners, from the turn of the century into the 1950's. Production on the Sheldon, which became one of the largest mines in the Lynx Creek watershed, peaked in the 1920's when its shafts had reached the 92-m (300-foot) level. Mixed ores from the mine were carried by rail from Walker, through a tunnel under a mountain, to the mill at Polant Junction. During this period, dewatering (removing water) became prohibitively expensive, so a decision was made to rework the tailings. This involved regrinding the tailings, then, through a flotation process, separating out the residual heavy metals. The slurry containing the final residue was then transported in a wooden pipeline to the present Sheldon Mine tailings pond, where it was dumped. By 1936, copper, lead, gold, and silver, then valued at a total of $1,075,000, had been removed from the mine. In the 1950's, the mine was reactivated, with workings extended to the 183-m (600-foot) level. The operation, however, was eventually abandoned as the cost of dewatering again became prohibitively high. The buildings at the site were

Fig. 1 The Sheldon Mine tailings pond produced severe erosion.

Fig. 2 The Sheldon Mine dump covered approximately 1.8 ha (4.6 acres).

eventually removed and the main shaft was plugged and covered over, leaving only a large dump and tailings pond covering approximately 1.86 ha (4.6 acres) and 1.42 ha (3.5 acres), respectively (figs. 1, 2).

ECOLOGY OF THE LYNX CREEK WATERSHED

General Description

The Lynx Creek watershed covers an area of approximately 7300 ha (18,038 acres) and is located in a semiarid region having a mean annual precipitation of 47.42 cm (18.67 inches). Usually, most of the precipitation occurs in late summer in the form of localized afternoon thundershowers. Milder and more generalized storms occur in the winter, with nearly half of the precipitation in the form of snow, which may accumulate to a depth of 1 m (3.3 feet). At other times of the year, precipitation is rare. Consequently, flow in Lynx Creek is greatest during periods of spring snow melt and summer rains. Its annual stream flow varies from 500 000 to 2.5 million cm (132 to 660 million gallons) of water, with an average estimated at approximately 700 000 cm (185 million gallons) per year. Finally, the elevation at the Sheldon Mine is approximately 2 012 m (6,600 feet).

Within the watershed, the soils are predominantly granite and schist in origin, and the slopes range from 30 to 60 percent. Generally, the soils tend to be shallow and contain considerable amounts of gravel with a texture of loam to silt loam. Also common are areas with stones and rock outcropings. Finally, the dominant vegetation type is ponderosa pine associated with several species of oak, mountain mahogany, and black walnut. Several species of grass are also present.

The Ecological Problems of Lynx Lake

In 1963, the Arizona Game and Fish Department constructed a dam on Lynx Creek approximately 16 km (10 miles) southeast of Prescott, creating Lynx Lake (fig. 3). A campground was constructed near the 22.26-ha (55-acre) lake, which was primarily intended to be a recreational facility offering cold-water trout fishing. Unfortunately, the water quality of Lynx Creek was not tested before construction of the dam. Eventually, it was discovered that populations of cold-water trout cannot be permanently established in the lake. It is thought that this is due to the presence of sediments, which make the lake water toxic to many algal species and other organisms in the food chain of the trout.

A rather high rate of erosion in the watershed results in an annual flow of about 2 900 cm (102,000 cubic feet) of sediment into the lake. Most of this sedimentation occurs during periods of peak flow in the creek. Preliminary studies by the Arizona Bureau of Mines, the Arizona State

Fig. 3 Lynx Lake was the recipient of erosion from the tailings pond and mine dump.

Department of Health, and the State Game and Fish Commission identified the presence of high levels of manganese, copper, cyanide, arsenic, zinc, and sulfate in the sediments. Further, drainage from the Sheldon Mine and its tailings was indicated as a probable major source of these toxic substances.

RECLAMATION OF THE SHELDON MINE DUMP AND TAILINGS POND

Treatment Objective

The primary objective of the reclamation project concerned improving the aquatic balance of Lynx Lake through reduction of the flow of sediment and toxic materials in Lynx Creek, and improving the esthetic quality of the watershed.

Analysis of the Tailings

A preliminary examination of the watershed indicated the presence of numerous surface disturbances and drainage from underground mines that have the potential to contribute toxic materials to Lynx Lake. These disturbances include numerous prospects and small mines with tailings ponds, waste dumps, and shafts. Also present are exposed ore-bearing formations, private roads, residences, and grazing areas that collectively contribute toxic runoff to Lynx Creek. However, the largest disturbed areas within the Lynx Creek watershed were the Sheldon waste dump and tailings pond.

Analysis of samples from the Sheldon waste dump and tailings pond indicated that they consisted largely of quartz, feldspar, pyrite, sericite, and limonite, as well as high concentrations of heavy metals. The samples were highly acidic. In addition, analysis of water leached from the waste dump, from a lateral working beneath it, and from the tailings pond showed that it contained high concentrations of soluble salts of copper, lead, zinc, iron, and sulfur. Finally the bed of Lynx Creek, between the Sheldon Mine and Lynx Lake was also laden with toxic sediment. This information, combined with the fact that the Sheldon is the largest abandoned mine in the Lynx Creek watershed, indicated that it was probably the major source of the ecological problems of Lynx Lake.

Approach to the Problem

While the preliminary analysis indicated many sources of toxic chemicals in Lynx Creek, it was not economically possible to treat them all. The highest priority was given to the treatment and reclamation of the Sheldon waste dump and tailings pond. While the project focused on treatment of the Sheldon Mine site, it was acknowledged that a complete solution to the problems of Lynx Lake would probably require eventual treatment of many additional sites and the sealing of at least one lateral working that drains into the creek from beneath the Sheldon waste dump.

Various treatments were selected that would serve to improve the quality of water in Lynx Creek and the appearance of the project site. These include surface recontouring, detoxification of surface tailings and waste-dump material, control of drainage from the dump and pond, diversion of offsite water around the dump and tailings pond, and revegetation of the site through seeding and planting.

Treatments

Dewatering. The first treatment undertaken at the site included draining the standing surface

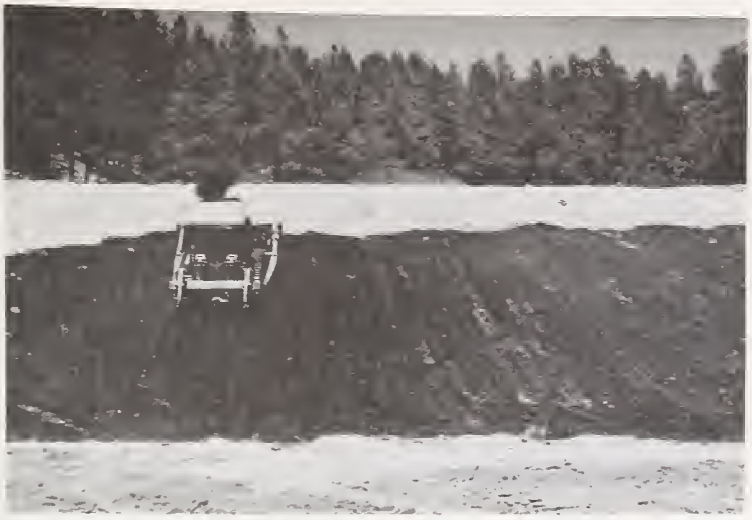

Fig. 4 Topsoil was applied to the tailings pond 'at a thickness of .15 cm (6 inches).

and subsurface water from the tailings pond by trenching. This was done several months in advance of subsequent treatments to make the pond surface workable with heavy equipment.

Recontouring. Recontouring the pond and dump is designed to modify or eliminate irregularities of snape, create more gentle and stable slopes, retain moisture that falls on the site, and prevent or control runoff from adjacent ground onto the treated sites. To accomplish this, existing erosion gullies were filled in and compacted. In general, recontouring is designed to blend visually with the surrounding landforms.

Soils and amendments. To neutralize the surface acidity of the tailings, a layer of limestone (approximately 75 000 kg/ha) was applied to the entire tailings area, then overlaid with 30 cm (1 foot) of alluvial topsoil. Then the topsoil was compacted to a thickness of about 15 cm (6 inches) (fig. 4).

Revegetation. The primary intent of revegetation is to reduce surface runoff. In this case, a mixture of grasses and legumes was selected, because the subsurface conditions were deemed unsuitable for the growth of trees, and it was desirable to establish a permanent organic soil layer as rapidly as possible. Approximately 18 kg/ha (16 lb/acre) of seed were used. The seeds were either broadcast or mixed with a hydromulch composed of water, wood fiber, and a petroleum-based emulsion. This emulsion is used to stabilize the material against wind dispersion. Then, the drip irrigation system was installed.

Drainage control. Diversion channels are constructed to shunt offsite drainage around the treatment areas. Onsite water flow is controlled by terracing of the steeper slopes into smaller runoff areas and impounding the water in swales, which dissect the slope.

Esthetic consideration. Surface recontouring is designed to conform to the surrounding natural landscape. In this case, a protective fence was constructed of rails so that it blended with the rustic setting.

Early Effects of Treatment

After 1 year, the physical appearance of the tailings was greatly improved. Good grass cover was present and naturally seeded trees were becoming established. Two followup lime treatments have been required and maintenance of peripheral drainage channels has been necessary.

WHAT WAS LEARNED FROM THE LYNX CREEK PROJECT?

This section discusses a variety of specific problems that arose in connection with the project. Also included are other observations that may be of value to those attempting similar reclamation projects.

LIME APPLICATION

Supplemental lime applications were required at the site, indicating the need for careful planning concerning the amount and quality of the lime that is used. Traditional agricultural rules concerning the amount of lime to be applied per hectare (acre) do not necessarily apply to highly acidic waste materials. It is suggested that site-specific analysis of the waste materials be made and that the quality and quantity of lime required be experimentally determined. Further, the method of lime application is important. For example, in this situation, surface application is not highly effective. The possibility of placing lime in pits or auger holes distributed at intervals might be investigated as a means of treating waste materials to a depth of several meters (feet).

TAILINGS POND DEWATERING

While the Sheldon pond was drained several months in advance, difficulties were still encountered in the course of subsequent treatment with heavy equipment. This indicates that care should be taken to remove the water from the pond far enough in advance to allow for settling and for the surface to become workable. It may be necessary to dewater at least 1 year before subsequent treatment.

TOPSOIL SELECTION

Topsoil needs to be selected for texture, available water holding capacity, organic content, and spreadability. For instance, silty loam would be superior to alluvial soil having low clay content. Also, the presence of rocks of moderate size, up to 0.3 m (1 foot) in diameter, can be of value. This is because they can be "walked" in with a caterpillar and will serve to both anchor the soil and provide small areas of disturbance that will foster the development of plant cover. Finally, the depth of applied topsoil must be adequate to support full development of the root structures of the planned vegetative cover species.

SLOPE ABUTMENTS

At Sheldon, it was found that gabion structures are highly effective and durable, both as retaining devices and to protect water channel banks at locations subject to serve water forces.

SEEDING

Hydroseeding with petroleum-based fiber mulch proved to be well suited for use on surfaces of the treated waste dump and tailings pond (fig. 5). The mulch has adhesive properties that protect the fibers from wind and water erosion. Attempts were made to establish tree seedlings, but the topsoil layer was not deep enough to support them or to protect their roots from chemicals contained within the waste materials below. Therefore, it is recommended that tree seedlings be planted in pits, of a depth and diameter of about 1.2 m (4 feet), that have been given

Fig. 5 Hydroseeding operation on the mine dump.

an adequate protective layer of lime and then filled in with topsoil. This should provide a good substrate for the trees, until they have reached a moderate size.

IRRIGATION SYSTEM

The drip irrigation system that was installed at the site proved to be economically impractical to maintain. This aspect should be considered in the design of such systems.

SITE PROTECTION

Disruption of the site by grazing animals and motorcyclists indicated the need for protective fencing. Heavy fence rails have been found to be more effective, esthetically pleasing, and durable, than small ones.

PRELIMINARY SITE EVALUATION

Careful preliminary evaluation of a site should be made, particularly with respect to the magnitude of the treatment that will be required. At this time, all aspects of the site's problems should be identified, and adequate funding set aside for their effective treatment. Incomplete treatment or undertreatment can seriously undermine the overall effectiveness of a project and result in the need for costly supplemental treatments.

Chapter Two

PLANNING THE RECLAMATION PROJECT

Introduction

One of the first tasks in planning a reclamation project is to determine the magnitude and extent of the impact of the disturbance to be treated. In beginning the planning phase, it will be important to identify the original ecological problems that made the project necessary, as well as anticipate project related problems that might occur in the course of the reclamation program. Careful analysis of problems in the planning phase should serve to minimize additional difficulties once the project is underway.

The planners will need to accurately ascertain the size and boundaries of the abandoned site and the extent of offsite lands that are ecologically disturbed by it. Also, it will be necessary to identify as many aspects of the ecological disturbance as possible. Then, specific objectives to be accomplished by the project treatment program should be devised. Usually, these objectives will be used to reestablish a harmonious relationship between the abandoned mine site and the remainder of the ecosystem of which it is a part. Also, the objectives will need to incorporate the planned future use of the land. Determining the future use of the abandoned mine site can be one of the most important aspects of the planning phase of a reclamation project, because it can significantly affect various phases of the treatment such as the final shape of the recontoured land and the selection of vegetative cover. The assessment process will require the gathering and evaluation of a variety of data for use in the planning process and, later, in the selection of specific treatment methods.

It is very important that the planner be aware of the fact that there may be important social, political, and economic aspects to the original ecological problems and their remedies. For this reason, questions of past, present, and future land use; ownership; and jurisdiction assume an importance nearly equal to that of ecological considerations in the planning process.

This chapter raises certain key questions that confront the planner in the formulation of a mined land reclamation program. Due to the individual nature of each abandoned mine site, these questions must be discussed in generalities, because specific answers can only be ascertained by the planners for their specific project application. Undoubtedly, the questions raised here will only be harbingers of many specific and sometimes difficult questions that will be encountered in the course of planning a reclamation project. Primarily, this chapter is concerned with developing an overall grasp of a project through the identification of existing and potential problems, data gathering and analysis, and project objective outlining. Following is an attempt to list some of the more important problems that may be encountered by project planners. Like the questions, specific problems will vary from site to site. The selection and planning of specific site treatment methods will be considered in Chapter 3.

Numerous situations will arise in both the planning and operational phases of a project where expert advice will be invaluable. Judicious use of expert technical and legal advice can result in significant savings of both time and money. In some situations, it may make the difference between the ultimate success or failure of a reclamation project.

WHAT ARE THE BOUNDARY CONDITIONS OF THE DISTURBED SITE AND THE AFFECTED ECOSYSTEM?

In planning a reclamation project, it is essential to be certain of the legal, physical, and ecological boundary conditions of the abandoned mine site and adjacent or downstream lands that are affected by it. Legal boundaries will affect

ownership and jurisdictional questions that may arise in connection with the project. The physical boundaries of the site, and the extent of the ecological disruption produced by it, will determine the extent of the area to be treated. The latter information will also aid in the identification of other sources of disturbance not located on the proposed treatment site. Some of the required information may be obtained from topographical maps and records, while drill cores and land surveys may be necessary to ascertain the volume of the tailings and the physical extent of the disturbance. This knowledge is essential when estimating the magnitude of the reclamation effort to be undertaken.

Also, it is essential to recognize and understand the roles of the various component parts making up the ecological systems within the watershed and how these parts are affected by the disturbance. These components will include the terrestrial, aquatic, and atmospheric phases of the physical environment and the animate, vegetative, and microbial sectors of the biotic phase of the system to be treated. Life forms that live in the soil must also be considered.

Frequently, planners will encounter problems when they find that boundaries, whether politically or scientifically delineated, are generally arbitrary by nature. Ecosystems transcend boundaries devised by humans; therefore, so may the ecological impact of abandoned mine tailings. For this reason, project planners may have to arrange for treatment programs that cross jurisdictional boundaries and property lines and, even in cases where this is not feasible, it should be recognized that the impact of the treatment may transcend such lines. Related to this problem is the fact that jurisdictional matters may also prohibit the elimination of environmental problem sources located upstream from the mining site in the watershed, even though they directly affect the abandoned mine site and contribute to the problem ascribed to it. In such cases, alternative solutions may have to be found.

WHAT KINDS OF PROBLEMS HAVE BEEN PRODUCED BY PAST MINING ACTIVITIES?

One of the major tasks that must be addressed in the planning of a disturbed area's reclamation is the accurate identification of the exact nature of the problems that have resulted from the land disturbance. A good first step is to prepare a detailed list of all of the problems that have been attributed to the disturbance and to order them into useful categories. The specific categories selected may vary from site to site, but they might include water quality, soils, vegetation, and land use. Most of the problems produced by an untreated site can be separated into two major classes: (1) those that affect environment; and (2) those that directly affect people. Although there will be some overlap, this distinction can be an important one, because it may become necessary to "sell" a project to landowners. In such a situation, it will be valuable to be able to show people how the ecological problems of the site adversely affect them with regard to such practical considerations as land use, property values, and taxation.

Environmental Problems

In the course of problem analysis, it is important to determine whether each listed item is an effect of the disturbance caused by the abandoned mine, or derives from some other source. For example, if a lake or stream cannot support a population of fish, the source of the pollution could be local sewage, rather than contamination of the water by chemicals from an abandoned mine. Such questions can often be resolved only with the aid of field or laboratory analyses. The following list suggests some possible environmental problem areas:

- Reduction of surface and/or ground water quality by toxic chemicals from tailings ponds and waste dumps that may adversely affect animal and/or vegetative life.
- Reduction of air quality by dust from the abandoned site where vegetation cannot grow.
- Alteration of the microclimate due to large land areas devoid of significant vegetative cover.
- Destruction of onsite and downstream animal habitats by such things as mud-

flows, sedimentation, and chemical leaching.

- Erosion and related problems, such as destruction of soil surfaces, destructive alteration of the landscape, and silting of water bodies downstream in the watershed.
- Physical and vegetative disruption that results in reduction of the esthetic quality of the disturbed site and the creation of visual disturbances that are detrimental to land elsewhere in the watershed.

Social, Political, and Economic Problems

In the planning of a technological project, it is often easy to lose sight of people-oriented problems. This class of problems has two components that importantly relate to reclamation projects: (1) problems, which are generated by the site, that affect people; and (2) problems, which are generated by people, that will directly affect the project. In the first category, esthetic and ecological disturbances produced by the site can adversely affect property values and land-use potentials elsewhere in the watershed. This is particularly true when water quality is affected to preclude its domestic, agricultural, or recreational use. These affected property values will in turn affect both regional prosperity and the tax base. At this level, the problems generated by the site may take on political connotations. The second category of potential people involvement in a reclamation project is discussed later.

IS THE PROPOSED USE FOR THE RECLAIMED LAND SUITED TO THAT SITE?

Before this question can be properly addressed, various factors involved in the determination of possible uses for the land must be considered. These factors include the physical, chemical, and biological limitations of the land, as well as socioeconomic demands and prohibitions. For example, it is possible that ore-bearing outcrops and/or mines elsewhere in the affected watershed may contribute toxic materials to downstream sites. For a variety of ecological, legal, or social reasons, it may not always be possible to correct these situations. Therefore, land-use plans for the site to be reclaimed may have to be altered. The following is a list of items that will need to be considered in this context:

- Toxic chemicals may be present in the waste materials and may permanently limit the potential vegetative growth or possible uses of the disturbed site.
- Site-imposed biological limitations can restrict the eventual development of vegetation or animal life on the site. For example, the potential for vegetative climax on the site may not be equivalent to that on adjacent land.
- Possible adverse environmental affects of the proposed uses of the land need to be considered, such as: Will the proposed land use significantly increase auto traffic? Will it increase human population density and place a strain on water supplies and sewage disposal? Will pressures for commercial or residential development and utility installations be increased?
- Are there physical limitations to the possible uses of the site that are imposed by surface contours or obstacles?
- Are there political or legal restrictions that may limit possible uses for the land? Is the land under public or private ownership? Are there specific zone or unit plans or restrictions?
- Are there limiting social or economic factors that will affect the possible uses of the land? The value of the land will economically determine, in part, its relative suitability for agricultural, recreational, or alternative uses that offer greater economic return.
- Does the land offer a high natural potential for some particular use such as recreation? Related considerations include ease of access to a site and its proximity to human centers, special features such as bodies of water or usual scenic or historical interest, and existing vegetation that

might offer potential camping or picnicking sites.

A key question is whether or not a treatment program will be able to overcome physical, biological, and/or chemical limitations such as those listed above. A variety of options may exist for possible use of a site, including recreation, agriculture, residential, commercial, or possibly no specified use at all. Some reclamation projects may be undertaken for the protection of adjacent or downstream land or for esthetic improvement of adjacent land, rather than by way of interest in the primary mine site itself. The possible options and the use selected will be different for each treatment site, and the decision made will affect the objectives of the reclamation project. Where possible, it will be desirable to include input from local area inhabitants in making the final land-use determination.

WHAT ARE THE OBJECTIVES OF THE PROPOSED RECLAMATION PROJECT?

After ascertaining the ecological problems associated with the site and deciding on a prospective use for the reclaimed land, specific reclamation objectives should be outlined. While the particular set of objectives prepared for a given project will depend on the individual situation, certain general criteria need to be considered in their formulation. For instance, the objectives should be both logistically and financially feasible, while meeting with general public acceptance. Also, they must be acceptable to those responsible for the management of the disturbed land and the affected watershed. In addition, the project should be aimed at producing environmentally sound and stable conditions that will ultimately reintegrate the disturbed area into the general ecosystem, while alleviating as many of the initially perceived problems as possible. Minimally, the project objectives need to bring the site into compliance with applicable Federal, State, and local environmental quality regulations and existing legal and safety standards.

WHAT KINDS OF INFORMATION AND DATA NEED TO BE COLLECTED IN THE PLANNING OF A RECLAMATION PROJECT?

The majority of data required for planning a successful project may be categorized as: environmental; historical, with respect to mining operations and other past land uses of the site; and social, economic, and political factors that may relate to the reclamation of the site.

The data gathered will be useful in formulating realistic objectives for the reclamation project and/or tne assessment of alternative land uses. For example, water analysis data will indicate those kinds of treatment that will be necessary to improve water quality. Plant inventory data from the ecosystem surrounding the disturbed area will suggest the best species to reintroduce to the disturbed land. Hydrological and meteorological data will aid in determining the necessity of recontouring the disturbed area. Sociological data will help to ascertain the necessity for, and best approach to, public relations work before implementing the planned project.

Once the treatment of the site is underway, the collected data will assist in assessing the progress of the project and evaluating its ultimate success or failure, long after completion.

WHAT TYPES OF ENVIRONMENTAL DATA WILL BE NEEDED?

In addition to listing the perceived problems of the ecosystem or watershed affected by the disturbed land, and those of the disturbed site itself, it will be necessary to conduct various surveys and analyses to establish baseline or "normal" levels for the different components of adjacent, undisturbed portions of the ecosystem. This data can be compared with information taken from the disturbed site before, during, and after the treatment program. The specific kinds of data that should be gathered will vary with the particular site and might include, but not be limited to, the following items:

- Land and hydrological surveys of the disturbed site are important in determining

its precise relationship to the remainder of the watershed. Hydrologic data aid in determining the necessary treatment methods, and assessing the potential for contamination of water supplies elsewhere in the watershed. Also, a survey of the site should be made to ascertain potential hazards above and below the surface resulting from past mining activities and from such natural phenomena as landslides, snow avalanches, mudslides, and flooding.

- A drainage map is useful in several ways including planning of drainage from the site and protection of the site from erosion. Also, the map is useful in locating possible sources and/or concentrations of contaminating materials derived from the site to be treated, or other locations in the watershed. Finally, the map should note the location of roads, other mines, mineralized outcrops, construction sites, buildings, and grazing patterns in the watershed. These items offer potential for erosion and the introduction of sediment and/or toxic chemicals into the drainage system of the watershed.

- Meterological data are valuable in planning recontouring of the land surface, revegetation methods, and species selection. This information aids in predicting flood and erosion potential and determining possible need for establishing microhabitats to assist revegetation and repopulation of the site.

- Water quality data provide information for the planning of treatment methods to bring about compliance with environmental standards.

- A mineral analysis of tailings from the pond and waste dump, including core samples to ascertain the extent and chemical composition of tailings and their potential for contaminating surface plants and water supplies, is essential for intelligent planning of reclamation treatments. This information can be an important factor in planning movement of waste materials in the recontouring process. It is important to note that the chemical content of the tailings may significantly differ with respect to depth and horizontal position in a given pond or dump.

- A vegetation analysis is needed to compare the disturbed site with adjacent land in the ecosystem. Obtain species lists and note plant distribution and density. These data should be considered along with meteorological and other abiotic environmental data in determining the vegetational climax potential of the disturbed site.

- Obtain wildlife data from the surrounding adjacent land. Then combine this information with data concerning food chains on the adjacent land to ascertain the potential zoological population composition and density for the reclaimed disturbed site. This information is also valuable when planning possible surface restructuring so as to provide niches for certain species.

- A visual analysis of the disturbed site and its surroundings is an important aid in planning esthetic improvements. The visual analysis should include such data as the locations of points in the surrounding area from which the mine is visible and the scenic quality of the surrounding landscape.

- Photographic surveys aid many aspects of data gathering, project planning, and postproject monitoring and evaluation. These surveys should be made before, during, and after treatment of the site. It is important to establish specific camera sites that can be used for subsequent photography of identical views. Also, it may be useful to document the project with motion pictures and/or video tapes.

WHAT HISTORICAL INFORMATION CONCERNING PAST MINING OPERATIONS AND LAND USE WILL BE OF VALUE?

Information of a technical nature regarding past mining operations on the reclamation project site can be valuable both from the standpoint

of project safety and its ultimate success. This kind of information might include surface and/or underground maps showing shaft locations. Two examples of this point were experienced in connection with the Sheldon Mine reclamation project. In one instance, a large and deep vertical shaft, which had been superficially covered, was accidentally discovered by a heavy equipment operator. Potentially this was a dangerous situation. The other example is provided by the presence of a lateral working located beneath the waste dump which, for significant periods after rainfall, drains chemical-laden water into Lynx Creek. If detailed maps showing the locations of the workings are available, the water might be diverted before it enters the mine.

Technical details of past mining activities on a given site may be difficult to locate, and there is no guarantee that such information even exists. But the potential benefits to be gained from such information will make the effort worthwhile.

WHERE CAN INFORMATION ABOUT THE WORKING HISTORY AND STRUCTURE OF A MINE BE LOCATED?

If any former operators of the site are still in existence, historical information may be relatively easy to obtain. In many instances, however, the company or companies will no longer exist and operations records may have been destroyed, lost, or may have come into the possession of an executive, engineer, geologist, or their families. Sometimes, such records find their way into archives, libraries, or other repositories. The search for this kind of information may require considerable time and effort. Often, reference librarians and archivists are willing to offer their expertise in helping with the search. The following list suggests a few types of agencies that may have files containing historical information and maps. The exact names and kinds of agencies will vary from state to state (the examples given here pertain to Arizona):

- Mine bureaus and departments of mineral resources: These agencies may be State or Federal. Some may have detailed records of many large and small mining operations. Sometimes, these records may include maps of workings and their locations. In Arizona, such records are maintained by the Department of Mineral Resources in Phoenix, and microfilm copies of a portion of these files may be found in Tucson at the Bureau of Mines.
- State mine inspectors: In Arizona, State law requires all mine operators to make detailed operation maps and information available to the Mine Inspector on request. Such materials, however, are not kept on file by that office. Laws concerning what must be filed with mine inspector offices will vary from state to state.
- State archives: State archives are usually maintained in State capitols. They may contain detailed maps of certain mining areas and sites. In Arizona, the State archive collection contains shaft schematics for approximately 100 mines, both large and small.
- State corporation commissions: Agencies governing corporations will usually maintain files of articles of incorporation, including the names of the incorporators and dates of incorporation and dissolution. This information may be of value in locating such persons or their families.
- Libraries, museums, and historical societies: Public and university libraries, museums, and State or local historical societies often maintain special collections including maps, photographs, personal papers, and newspapers. These may contain detailed information about mining districts and individual mines. Staff members of such agencies are invariably helpful in searching for such information.
- National archives — Territorial records: In some cases, a particular mining operation may have been carried out in territorial days prior to statehood. Certain States maintain territorial records that predate the kinds of State agencies listed above. In other cases, such information may be kept by the Federal government in regional depositories of the National

Archives. These are located in Laguna Nigel, California (records for Arizona, southern California, and Clark County, Nevada); Denver (records for Colorado, Montana, Utah, and Wyoming); Fort Worth (records for New Mexico); San Francisco (records for northern California and Nevada); and Seattle (records for Alaska, Idaho, Oregon, and Washington).

It should be remembered that even if detailed workings location information is found for a given site, such records may be out of date. For this reason, safety precautions should always be observed.

Social, Economic, and Political Data

Earlier in this chapter a distinction was made between the effects of an abandoned mine site and its reclamation on people and the ways in which people can affect a reclamation project. Both of these may be considered people-oriented problems, which must be addressed by reclamation project planners.

For this reason, a program of public relations and involvement of the public in planning reclamation projects can be beneficial. Public opposition to a project could conceivably come from several directions. For example, owners of neighboring land might object to the reclamation of a site by reason of feared potential damage to their land, an increase in the tax base of their land, or objections to the proposed use for the reclaimed site. Such objections must be met by planners with diplomacy and from a position of factual knowledge about the real benefits and problems to be derived from the reclamation of a site.

In this regard, an essential question to be addressed by the planner is whether or not the proposed treatment will adversely affect, or be publicly perceived to adversely affect, offsite land elsewhere in the watershed. If so, what will be the actual effects and how great will be their magnitude? It is important to be aware of the fact that many of the problems encountered in planning may appear to be simple ecological matters, but may in fact be extremely sensitive from a sociopolitical point of view. The following list of topics is intended as a guide for consideration by the planner. It is not all-inclusive, however, because various other matters may arise as the planning of a project progresses.

Legal matters (additional legal considerations are discussed in Chapter 3). Legal research is required to find out about laws regarding land use and environmental standards, such as air and water quality. This research should be done at the local, State, and Federal levels.

In addition, a variety of questions related to land ownership must be addressed. One question might be who owns or has jurisdiction over the land on which the abandoned site is located (it is important to distinguish between surface and mineral rights). Another is who owns land elsewhere in the watershed that is adjacent to or affected by the disturbed site. A third question might be is there a possible need for condemnation of the land. Finally, will there be a need for expenditure of public funds on private land, which can be a possible source of legal and political difficulties?

Topics related to land use. It will be necessary to define the present major uses of the disturbed site and of land elsewhere in the watershed that is affected by the site in one way or another.

Also, the land-use history of the impacted site(s) should be examined. The present land use of the site and land elsewhere in the watershed must be considered when ascertaining the future use of the site. If the project will alter traditional land-use patterns at or near the site, considerable resistance to the project may be encountered.

In addition, it will be necessary to determine the legal options for potential land use.

Finally, the following questions should be asked. Is the site easily accessible? Would easy access to the site pose a danger to life or limb? Does accessibility affect the options for future use of the site?

Public opinion. Public opinion and perceptions related to the project must be solicited and the information incorporated into the planning process. To do this, public opinion surveys and/or hearings may be used. Also, some concerned citizens may wish to become involved in project planning.

In addition, it is recommended that the relative importance of land-use patterns, past, present, and projected, to local residents be assessed. Find out whether there is a public "consensus" concerning the best use of the disturbed land.

Other questions you might ask include: How are the problems produced by the disturbed site (such as water quality, dust pollution, and damage to the recreational potential of the watershed) perceived? Are there specific factors related to the proposed project that may generate public opposition?

Finally, is the public aware of the benefits that will accrue from the project?

Economic factors. It is advisable to determine the potential economic impact of the reclamation project and its consequences.

Also, the economics and energy efficiency of possible treatment alternatives should be assessed in advance of their planning.

Finally, will reclamation of the disturbed site increase on or offsite tax values? If the answer to this question is yes, considerable resistance to the project may be encountered.

Historical and social factors. Historical data concerning the environmental, social, and economic impacts of any previous reclamation projects in the area should be examined.

In addition, an effort should be made to understand the cultural values of the people living in the area adjacent to the project site, particularly as these values relate to land use.

Esthetic factors. The following are some questions that should be asked. Is the site highly visible? Is the esthetic impact of the site important to local inhabitants? Can the esthetic impact of the abandoned mine be significantly improved by the reclamation project? Is the site visible from more than one vantage point; if so, how many points and which are most critical? Is the surrounding area noted for any unique visual features? Do people visit the area because of its visual quality? Does the area have national, regional, or local appeal? How many people see the site? What distance or distances (foreground, middleground, or background) is the site from the viewer and which are most critical? What are the strongest visual elements (form, line, color, texture) in the surrounding landscape? What is the inherent scenic quality of the surrounding landscape? What is the visual management objective or objectives for the surrounding landscape?

Chapter Three

FIELD OPERATIONS

In writing this guide, a distinction was made between the overall planning of a project and the planning of specific field operations necessary to carry out the treatment. Generalized project planning is the subject of Chapter 2, while this chapter addresses the specifics of preparation for actual work at the project site and some problems that might be encountered during the operation.

Sometimes, reclamation projects are complex, so the joint efforts of a number of individuals and organizations may be required. Participants in a project might include landowners or managers, regulatory agencies, contractors, laborers, engineers, scientists, and perhaps, interested representatives of the public. As discussed in Chapter 2, it is important to promote good public relations.

In addition, in each phase of planning, and during the operational phase of the project, it is important to promote communication and cooperation between all of the parties involved. This objective can be partially met by keeping everyone concerned advised of the project's purposes, plans, and time schedules, and of any subsequent alterations.

What Are the Major Steps in Planning a Successful Reclamation?

First, consider the site, its problems, and the overall treatment objectives. For those who will be intimately involved in the planning and execution of the operational phase of a project, familiarity with the physical site, its boundary conditions (see discussion of boundary conditions in Chapter 2), and the overall plans of the project are needed. A thorough understanding of the ecological problems of the site (or offsite problems generated by it) and how the desired results are to be accomplished by the proposed treatment will provide a background essential to the effective planning and performance of a project.

Second, learn about the framework of regulations and restrictions that apply to the site and within which the reclamation operation must be conducted. In this regard, operators and planners should become familiar with the regulations and standards for environmental quality and legal restrictions that must be considered in implementing the project.

OTHER MAJOR STEPS

Prepare operational plans. Specific operational objectives and plans for the project should be prepared for each phase of the operation. When drafting these plans, careful consideration should be given to all alternative treatment methods with respect to effectiveness in meeting treatment objectives, environmental effects, and cost and operational efficiency.

Contracting. Determine whether the project can be effectively handled "inhouse," or if the services of an outside contractor are required. In the second situation, obtain the services of a contractor who is able to competently execute the treatment operations.

Equipment needs. Equipment requirements must be ascertained in relation to various logistic and cost-benefit factors. The equipment selected should be practical from the standpoint of transport to and operation at the site, while making the best use of available labor and materials within the framework of scheduling requirements. Also, fuel consumption efficiency must be taken into account. This will be the responsibility of the contractor who is hired.

Scheduling operations. It is recommended that a detailed schedule of operations be prepared that considers restrictions imposed by the climate and the physical nature of the site and also coordinates such variables as the availability of supplies, equipment, and labor. As discussed in Chapter 2, it is important to plan for the execution of certain preliminary treatments (for ex-

ample, thorough draining of tailings ponds) well in advance of the major phase of other project operations.

Cost estimates. Estimates should be prepared for each phase of the project, including probable costs of viable alternative treatment methods. Remember, contingency planning is always useful.

Site-Specific Factors Affecting Individual Operations

A number of factors specific to each site can affect one or more of the individual operations of a reclamation project. These will include: treatment objectives; ecological, legal, and esthetic considerations; possible alternative treatment methods and equipment; and operations scheduling.

WHAT KINDS OF REGULATIONS AND QUALITY STANDARDS MIGHT APPLY TO THE RECLAMATION OF ORPHANED MINE SITES?

Reclamation projects can be subject to numerous regulations and standards imposed by many sources. It is possible to list only a few of the many kinds of restrictions that may be applicable and only a few of the many types of governmental agencies that might be concerned with their enforcement. Most regulatory questions should be dealt with in the initial project planning stages (Chapter 2). There are, however, some that directly apply to field activities in the treatment process. These will now be discussed.

Environmental quality standards and regulation

Environmental standards apply to reclamation projects in much the same way as they do to other activities that are potentially disruptive. While the end product of reclamation may be designed to improve environmental quality, care must be taken to assure that the treatment process itself does not generate water or air pollution, or otherwise adversely affect the environment. The particular standards that apply may differ widely with various situations. For example, water quality standards are generally based on planned water use, such as agricultural, industrial, or domestic.

In addition, some regulations may apply to offsite activities. For example, the removal of topsoil from a remote site for use on the reclama-project is subject to environmental protection regulations.

Environmental analyses, reports, declarations, and statements

Environmental analyses are required on Federal, as well as other categories of public land, for seemingly minor actions up to, and including, large projects. Consequently, environmental statements are required for any action that has a significant effect upon environmental quality, whether that effect is detrimental or beneficial. For example, on Federal lands, environmental analyses are required even for such small projects as the construction of a fence. Whether or not a statement will be required for action on nonfederal lands partly depends on such factors as ownership, the degree of potential disturbance (both on and off the site), whether or not there will be irreversible effects on basic resources, or whether or not there will be cumulative effects, chain reactions, or secondary effects. In addition, the uniqueness of a site, or the potential of a project for the generation of significant public interest, is also important in ascertaining the need for an environmental statement.

The determination of the depth of environmental analysis and the type of report required for a given project is too complex for detailed consideration in this handbook. The reader is referred to a guidebook written by W. F. Meek and to the book on environmental quality by the Council for Environmental Quality and the EPA (see Bibliography).

Safety and fire regulations

In many instances, fire and safety plans have to be filed before work on a project can begin. Blasting must be done by licensed individuals and specific warning procedures must be followed, along with posting of roads. In high-risk fire areas, there may be restrictions on certain activities or the use of certain kinds of equipment. Often, these matters will be taken care of by an outside contractor; but safety and fire prevention are the responsibility of each person working on a project site. A good source of information concerning fire prevention regulations and measures is the USDA Forest Service. It is important for personnel working on the project to be advised of fire regulations and plans.

Maintenance plans

In the initial economic analysis, maintenance cost and feasibility must be considered for each project. Detailed postreclamation maintenance plans may be required for some sites. Even if not required, it is a good practice to prepare such plans for each project site.

Information sources for standards and regulations

The numerous regulations and standards that may apply to a reclamation project are derived from many sources. Also, various Federal, State, and local agencies may be involved in enforcement, and may be in a position to provide information and interpretive assistance. In addition, ownership of the land greatly affects the regulations to which it is subject. At the Federal level, such agencies as the USDA Forest Service, Soil Conservation Service, USDI Bureau of Land Management, Army Corps of Engineers, U.S. Geological Survey, U.S. Public Health Service, and various environmental quality enforcement agencies may be able to provide information. Those agencies that should be consulted at the State level include those that regulate fish, game, water, and land use. The names of these State and local agencies may vary widely. Finally, area land-use plans may also provide information.

WHAT ARE THE SPECIFIC TREATMENT OBJECTIVES?

Specific objectives should be defined for each task in the reclamation project. For example, regrading may have several purposes including alteration of slopes to reduce erosion, improvement of the visual aspect, and provision of a surface suitable for specific land uses such as recreation and grazing. In addition to being incorporated into the original drafting of site plans, it is important that each of the objectives be understood by the operators performing the task. This is because they may need to make on-the-spot decisions regarding obstacles or other problems that could not be foreseen by the planners. Flexibility such as this, when allowed by planners and project managers, can greatly improve the end result of a project through encouragement of creative input and increased morale on the part of workers at all levels of involvement.

WHAT KINDS OF ECOLOGICAL CONSIDERATIONS APPLY TO OPERATIONS PLANNING?

A good rule of thumb to apply when planning project operations is to attempt, at each step, to integrate planned land use and the ecological objectives to the project with functional and esthetic design of structures and treatments. Also, it is both ecologically and economically wise to avoid overtreatment of a site. Treatment planning should attempt to maximize the use of existing features, which already provide some of the ecological functions that are project objectives. For example, if the process of natural revegetation is already well established, its destruction and subsequent replanting may be counterproductive unless other objectives, such as extensive regrading for drainage control, make it imperative. Even in such circumstances, alternatives to regrading should be closely considered.

If not already done in the initial planning stage of the project, a wildlife habitat and population inventory should be conducted on the site by a wildlife biologist. Personnel working on the project should then be advised of the results of the survey, including the wildlife present on and

near the site and the nature and locations of important habitats. Damage to habitats and their occupants should be avoided whenever possible. However, when destruction of important habitats is unavoidable in the course of treatment, it is a good practice to restore or replace them after completion of the project. Depending on land ownership and other circumstances, restoration and/or other special treatments may be mandated by project approval documents.

WHAT LEGAL ASPECTS SHOULD BE TAKEN INTO CONSIDERATION IN OPERATIONS PLANNING?

Questions of legality may enter into reclamation projects at several levels including contracting, land ownership and control, rules and regulations, and licenses and permits. In the latter third of this century, the environmental consequences of people's activities have become increasingly tied to our legal system. This section is not intended to give legal advice, but only to point out some of the more common ways in which legal questions may arise with respect to the reclamation of a small mine site. Many situations may require professional legal advice. Chapter 2 discusses several items that have legal implications in the context of initial overall project planning, such as boundary conditions and zoning restrictions. Also, there are legal matters that can affect later stages of planning and/or the actual operation itself. It is not practical to attempt to anticipate all legal questions that may arise in connection with a reclamation project, so only some of the more obvious ones are suggested here.

At the operational level, there are two main components of reclamation projects that may have legal ramifications: the planned effects of the treatment and the incidental "side effects" that affect the site or other land in the watershed. An example of the first situation is the intentional alteration of downstream water quality by reducing the concentration of salts leaching from a tailings pond into the watershed drainage system. Usually, when a change seems positive in nature, it is beneficial and does not generate complaints. If one effect of the treatment, however such as introducing high concentrations of treatment additives, is perceived to adversely affect water quality (albeit inadvertently), legal problems could result. Examples of the second situaiton are the generation of objectionable noise or air pollution by equipment, or perhaps an accidental spill of fuel, oil, or other toxic material into a stream or lake. Of course, there are other liabilities that are more traditional in nature, so they are usually covered by insurance. In some cases, it may be wise to investigate additional types of insurance coverage for a project. Please note that actual liability may differ, depending on the organization responsible for the project.

The potential for legal difficulties can be greatly reduced, if certain precautions are observed. These include insuring that each person involved in the performance of a project is familiar with the legal boundaries of the site, as well as with certain ownership and jurisdictional considerations and environmental regulations that may apply to the project. In some instances, the actual waste materials may extend beyond the site's legal boundaries, so workers must be advised of what portions of the dump and/or pond can and cannot be treated. They must also understand the need for protecting the treated site from problems caused by the untreated portion, and vice versa. Construction of temporary and/or permanent barriers against such things as human or animal access, and water flow or earth movement, may be necessary. In addition, it is important that all involved personnel understand as many of the potential effects of the various treatments as possible, both intentional and incidental. Those working in the field should know possible sources of pollution and how to minimize them. In some circumstances, alternative treatment methods may be desirable or necessary to minimize adverse effects.

Regulations concerning biological materials

In many states, there are legal restrictions concerning the removal and/or introduction of various species of plants and animals. In the case of endangered species, special permits and extensive protective measures may be required. The applicability of such restrictions to a particular site or areas in the vicinity should be explained,

both in letter and in spirit, to all concerned with a project.

HOW CAN ESTHETIC CONSIDERATIONS BE INTEGRATED INTO THE PLANNING OF FIELD OPERATIONS?

Scenic values and other esthetic aspects of environmental quality are of growing importance as public awareness and human population increase. Esthetic quality encompasses economic, psychological, and social components. Improving the esthetic value of a site should be a major consideration in the planning, treatment, and maintenance levels of a project. Frequently, a site's esthetic quality can be upgraded with relatively little impact on the overall cost of a project. Utilizing imagination and care in the planning, treatment, and maintenance stages of a project can do much to improve the esthetic value of a site. It is important for all the people involved to be aware of the fact that their own artistic sensibilities and skills will measurably affect the final esthetic appearance of the reclaimed land. Whenever possible, the assistance of a landscape architect will be valuable and should be obtained.

Blending of form and function

A major principle involved in improving esthetic quality is integrating practical function with pleasing form. A good rule of thumb to follow is to draw from the strongest elements of the adjacent landscape, such as form, line, color, and texture. For example, a waste dump is regraded in a manner that is visually harmonious with the surrounding landscape, or a fence provided to restrict large animals or vehicles from a site is both effective and pleasing when constructed of wooden rails, rather than chain links or barbed wire. Also, it may be possible to construct drainage channels that have the appearance and function of natural stream beds, rather than artificial ditches. Some of these techniques were successfully used in the Lynx Creek project.

Utilization of existing features and harmonious construction materials

In many instances, it may be both esthetically and economically desirable to preserve and enhance existing features on a site such as trees, interesting rock formations, established streambeds, and old buildings that blend with the surroundings. For example, existing rocks or boulders might be rearranged in a visually pleasing manner, or even used in constructing walls or retaining structures that would otherwise require introducing nonharmonious building materials from off the site. In addition to being less expensive than new materials, in some cases, building supplies salvaged from old structures can add an "antique" touch to new construction.

Selection and utilization of vegetation

Revegetation provides another opportunity for blending form with function. For example, trees and shrubs can form fences or traffic barriers. Frequently, ecological considerations may allow a degree of esthetic latitude with respect to species selection and planting arrangement. In instances where vegetation will not grow, a technology exists for altering the color of surface rock so that it blends with its surroundings.

Utilization of semipermanent treatment structures

In certain situations where it is necessary to erect structures for various reasons including establishing land contours and drainage channels, it may be possible to use semipermanent materials that eventually decay, or that may be removed after sufficient vegetation is established. This use of semipermanent materials will reduce cost and, in the long run, enhance the "natural" appearance of the reclaimed site.

WHAT FACTORS SHOULD BE CONSIDERED IN THE SELECTION OF EQUIPMENT AND ALTERNATIVE METHODS OF ACCOMPLISHING A PARTICULAR TREATMENT OPERATION?

More than one treatment method or plan may be feasible. These, however, may significantly differ in several aspects, while producing essentially equivalent results.

Energy use and economic considerations

As our energy resources become more restricted, the cost of a project in terms of energy use will become increasingly important. The economic cost of a project is directly affected by its energy cost. Therefore, the energy cost of alternative treatments and choice of equipment should be carefully weighed. Also, wherever possible, energy-intensive operations should be combined. An example of this is the combination of site recontouring with deep treatment of tailings and waste materials.

Fire hazard potential

Many abandoned mine sites in the Western United States are in forested areas. The potential for fire hazard should be considered both in choice between treatment alternatives and in selection of equipment. To meet certain standards, motorized equipment may be required. Also, it will be necessary to consider the effects of fire regulations and possible forest closures on work schedules.

Environmental effects

The environmental effects of treatment and equipment alternatives should be weighed on the basis of their potential for producing pollution such as dust, smoke, and noise.

Future land use

When selecting treatment methods and making seemingly minor decisions, the planned land use should be kept in mind. For example, small differences in grading, drainage control methods, or choice of vegetation can be important, if the land is going to be used for recreational purposes.

WHAT SHOULD BE CONSIDERED IN THE SCHEDULING OF FIELD OPERATIONS?

Scheduling is one of the most important and most complex aspects of operations planning. Scheduling will have a major effect on both the cost and success of a project. For example, unnecessary delays in delivery of materials can be expensive, in terms of idle equipment and operators.

Sequence of treatments for effectiveness

One of the top priorities in operations scheduling is planning for any necessary preliminary site treatments well in advance of the commencement of field operations. For example, if the treatment includes reclaiming a tailings pond, it must be drained (thoroughly dewatered) as much as a year before further operations on its surface. This permits manipulation of the surface with heavy equipment and allows for settling of the waste materials. Also, necessary permits should be obtained well in advance of preliminary treatments.

Logistical scheduling

There are two major classes of constraints and factors that must be taken into account: those that are fixed, inflexible, or otherwise not controllable, such as climate, seasonal economic factors, and population fluctuations; and those that are adjusted to optimize the flow of events during the project. For example, climate dictates when grading, chemical treatment, topsoiling, and planting can be done. Once the major time framework has been established to accommodate this inflexible constraint, materials, equipment, and labor can be scheduled.

WHAT SHOULD BE CONSIDERED IN THE ESTIMATION OF OPERATIONAL COSTS?

A number of items affect the total cost of a project:

- Administrative costs include those for planning, overhead, and payment of necessary fees and permits. Also to be considered are costs of contracting and general economic factors such as inflation. The effects of inflation should be integrated into long-range cost estimates for site maintenance.

- Site characteristics enter into the determination of cost. The size or the area to be treated is an important variable. For instance, onsite topography and climatic conditions may necessitate construction of drainage and erosion control structures such as gabions, diversions, or spillways. Also, site accessibility and distance will affect the cost of materials delivery. Finally, seasonal changes in accessibility should be considered.

- The quantities needed, price, and availability of materials such as chemicals, topsoil, mulch, seeds, and plants, must be taken into account, as well as labor and equipment costs. All of the above can be drastically affected by changes in local and national economic conditions, which are very difficult to foresee.

- All alternative treatment methods for accomplishing objectives, from waste neutralization to revegetation, should be evaluated for cost, as well as effectiveness. Differences between treatment methods, such as equipment and materials required, can result in large differences in cost.

- Financial responsibility does not end when reclamation treatments are finished. The maintenance costs of fences, access roads, and irrigation apparatus must be considered, as well as the possibility that some treatments such as grading and planting, may need to be repeated.

Chapter Four

RECLAMATION TREATMENTS AND PRINCIPLES

Ecological Problems and Treatment Objectives

Each orphaned mine site will present a unique set of circumstances and problems. Therefore, rather than attempting to present generalized "cures" for all problems, brief discussions explaining the relationship between various site problems and the methods of treatment are provided. In this chapter, topics deemed to be unique or primarily related to abandoned mine sites are covered in greater depth than those commonly discussed in the general literature on mining reclamation. For more detailed technical information on the various topics considered, the reader is referred to the sources listed in the Bibliography.

Generally, most of the ecological and esthetic problems of orphaned mine sites have both physical and chemical components. The physical disruption of the land results in excessive erosion and sediment production, while chemical contamination of the surface soil and water supplies is damaging to vegetative, animal, and human life. Some of the many possible approaches to the cure or containment of these problems are discussed in this chapter.

The overall treatment objectives for an abandoned mine site will vary from site to site. Generally, they will seek to control surface erosion, reduce chemical contamination of underground and/or downstream water supplies, and improve the esthetic appearance of the site. In some cases, the treatment will be designed to reclaim the land for a specific use, necessitating redesign of the landform. Many of the possible treatments address these functions simultaneously. Each mine will present its own unique set of conditions, but most of the above objectives can be met by the following treatments: regrading and filling in badly eroded areas in a manner that is harmonious with the surrounding landscape and suited to the projected land use; chemical treatment designed to reduce the toxicity of mining wastes near the surface; restriction of infiltration of surface waters into the waste materials; installation of structures necessary for the control of erosion and sedimentation produced by water from sources both on and off the site; application of topsoil and mulch to promote a good environment for vegetative growth; revegetation; and protection of the site during the early phase of its recovery. Many of the treatments will be of short or moderate duration, while others may require renewal. The ultimate goal of reclamation treatment is to establish temporary conditions that are gradually supplanted by natural processes. Usually, this goal is realized with the development on the treated site of mature vegetative growth that is ecologically harmonious with that on adjacent land.

Mine Dumps and Tailings Ponds

The term "tailings" commonly refers to the residue from ore processing operations that is put in a tailings pond (fig. 6). Waste material from underground mining is placed on a dump. There are significant differences between the materials found in waste dumps and ponds associated with a given mine. For this reason, they must be

Fig. 6 Tailings pond.

Fig. 7 Mine dump.

treated differently. Also, the exact nature of these materials differs greatly with the minerals being mined, the rock in which they occur, and the processing methods used.

Usually, the waste dump of a mine will consist of rocks and other residue from the underground operation (fig. 7). Waste dumps from underground mines are always much smaller, in volume and area, than the tailings ponds from the same mine. In most instances, waste materials from underground mines in the West will be acidic. Often, the materials in a waste dump are found as they were initially piled, at their angle of repose, although in many cases, the original structure may have been considerably modified by erosion. The material at the base of a waste dump is coarser than that at the top, because there is a natural segregation with the coarser and the fine material at the top of the dump.

In mountainous regions of the West, tailings ponds were usually impounded in small canyons or ravines behind dams constructed of mine waste materials. Frequently, the dams were built in stages by increasing their height as the ponds became filled with sediment. Abandoned tailings ponds may or may not contain water, either above or below the surface. The waste materials found in a pond differs considerably from that in a waste dump. Tailings ponds contain the residue from milling and chemical processing of the mined material. Often, the processing chemicals used were toxic, such as potassium cyanide. With time, some of the initial processing materials chemically change or break down, but others may remain in tailings ponds, along with ore residues, for a considerable period of time. Earlier extraction methods were less efficient than more recent ones, so older ponds may have a higher content of residual ore. This is also true of ponds that are gradually filled over a period of time where there is more residual ore at the bottom of the pond. Many ponds have been reworked so that their chemical content may vary in different parts. The consistency of pond waste materials is very fine and tends to be noncohesive If sufficient water is present, waste particles may exist as mud or slurry-like suspensions. In some cases, pond tailings can take on a gelatinous character.

Because abandoned mine reclamation primarily involves working with waste dumps and tailings ponds, an understanding of their nature is important to both planners and those working in the field. Accordingly, additional discussion on this topic is provided in the Appendix.

WHAT KINDS OF HAZARDS MAY BE ENCOUNTERED WHEN WORKING WITH ABANDONED MINE TAILINGS?

Of course, the exact nature of what remains in orphaned mine ponds and waste dumps over a period of years largely depends on what was being mined. If sulfide residues are present, the tailings may increase in acidity. Probably, this is the major ecological problem associated with abandoned mine sites. Aside from ecological considerations, those involved with reclamation projects should be aware of possible health hazards to workers from the tailings materials. It is good practice to observe appropriate precautions when working with abandoned mine waste materials. Therefore, a safety manual pertaining to the type of mine being reclaimed should be consulted.

An example is the inhalation of acidic dust, heavy metal residues, or silica dust. A further illustration is provided by radium mining operations, which set uranium bearing ore aside in waste dumps. Depending on the water content of a tailings pond and the consistency of the tailings, there may be a potential for spilling or outward flow of waste materials if a dam is breached. The effects of seismic activity should be considered at sites located where this is a possibility.

Fig. 8 **Grading of the waste material increases stability, reduces erosion and improves the esthetic appearance of the site.**

Fig. 9 **The final contour produces dramatic improvement in esthetic appearance.**

Also, in any old, abandoned tailings pond that is 15.24 to 30.48 m (50 to 100 feet) deep there is a possibility of isolated, saturated pockets of tailings that could be a trap for any piece of heavy equipment.

Physical Treatment of Abandoned Mine Tailings

The two major functions of recontouring mine wastes are to increase stability through reduction of erosion and improve the esthetic appearance of the site. Recontouring can also be tailored to a particular land use. Grading of waste materials can serve to modify or eliminate existing irregularities of form produced by past mining activities and uncontrolled erosion, create slopes that are less severe and more stable, and improve onsite conservation of precipitation (fig. 8 and 9). Also, recontouring can reduce the rate of erosion by decreasing the length and inclinations of slopes. If care is taken to blend the contours with the surrounding landscape, the end result of site recontouring is both esthetically pleasing and utilitarian.

Important components of most reclamation projects include regrading the site and construction of various devices for controlling erosion and sediment production. A variety of structures are possible; however, only a few will be discussed here. For detailed information on the planning and designing of erosion and sediment control structures, the reader is referred to the excellent series of EPA publications listed in the Bibliography. Control of erosion and sediment by nonstructural means, such as mulching and revegetation, is discussed later.

WHAT IS THE "OPTIMUM" SLOPE FOR RECONTOURED ORPHANED MINE DUMPS?

There is no universal answer to this question, but its consideration is of paramount importance to the success of a project. Unstable slopes are subject to slipping, which could bring about new exposure of mine wastes, destruction of surface vegetation cover, and loss of topsoil through rapid erosion.

In most dumps, the wastes are initially piled at the angle of repose for the specific type of material. The angle of repose is the maximum slope to which a material will pile and remain stable without surface slides. It is different for each kind of waste material. For example, the cohesiveness of clay is greater than that of sand; therefore, the natural slope of a pile of clay is greater than that of sand. In addition, the moisture content of a material affects its cohesiveness, permitting damp materials to be piled more steeply than dry materials.

There are several factors that should be considered in the selection of contour slopes: water runoff; esthetic appearance; and, the projected use of the reclaimed land. The velocity of surface water runoff is exponentially proportional to both the angle of inclination and length of a slope, or the greater the angle or longer the slope, the greater the potential for erosion. In this regard, it is important to consider the intensity and types of precipitation to which the site may be subjected. The intensity of rainfall events differ regionally. For example, desert and mountain areas in the Southwest regularly experience heavy rain storms of short duration that can produce rapid erosion, while other regions may be subject to protracted storms of lesser intensity or may receive the bulk of their precipitation in the form of snow. In addition, a site that is to be heavily vegetated can have steeper slopes than one that will remain barren, because the presence of ground cover significantly reduces surface erosion. The ability of equipment used for agricultural treatment or maintenance of the site to negotiate the slope should also be considered in determining the maximum angle for recontouring.

Often, the minimum slope contour is found through the necessity of containing a given volume of waste material within the confines of the surface area of the site. In most cases, it is prohibitively expensive, and possibly illegal, to remove waste materials from the treatment site. Therefore, the wastes must somehow be rearranged within the legal boundaries of the site so that they will not intersect water courses or unnecessarily cover additional areas of undisturbed land. Remember that the more steeply the waste materials are piled, the less land area they will cover.

In many situations, slopes of 10 to 15 degrees are considered optimal with respect to erosion, esthetics, and land use. Slopes greater than 30 degrees may create problems; therefore, the rapid establishment of vegetative cover on steeper slopes is particularly important.

HOW CAN WATER FLOW BE CONTROLLED?

Two sources of water are controlled in a reclamation project: water from off the site; and

Fig. 10 Ponded water can create very significant problems and needs to be controlled.

that which results from direct precipitation onto the site (fig. 10). Onsite water flow is controlled by vegetative cover and surface recontouring, while offsite water flow is controlled through diversion structures, channels, and impoundment structures.

Diversion structures are used to control or prevent erosive surface flow. Some of the methods used include breaking up long slopes that would be subject to rapid flow, and diverting sediment-bearing runoff into traps. The choice of structures depends upon several things including the anticipated water volume and velocity, slope, required structural permanency, ease of installation, and removal. In addition, provisions should be made to withstand 100-year flood conditions, if applicable to the site. Also, it is important to provide protective crossings over water channels for vehicle access, if necessary.

Design details of water diversion and conduction channels are rather complex, so the reader is referred to the aforementioned EPA series on erosion and sediment control for a more thorough treatment of this topic. Basically, channels may be of parabolic, triangular, or trapezoidal design, depending on site conditions, equipment availability, and other factors. The velocity of water flow in a channel will depend upon its size, gradient, surface texture, shape, and course. Protrusions or restrictions in a channel that produce turbulence will restrict water flow and may result in sedimentation or channel erosion (scouring). Erosion of the channel surface

Fig. 11 Gabion Structure.

Fig. 12 Diversion dikes help carry off water without erosion.

may be controlled by lining the surface with riprap (loose rock or aggregate) or planting grass in the channel. Erosion of channel banks at curves or intersections, which are subject to the force of high-flow velocity, may be controlled by the construction of straw dikes or gabions (dikes constructed of rock or aggregate baled together with wire mesh). Gabions are highly effective in the Sheldon Mine reclamation project at Lynx Creek (fig. 11). In the case of mineral mines, which produce corrosive or acidic wastes, the wire baskets retaining the rocks should be constructed of stainless steel. This material is available, because it is used in the construction of mill ponds and sea walls. Erosion may be eliminated by lining the channel with metal or concrete, but the expense is greater and such structures can be detrimental to the esthetic appearance of the site. Another way to reduce erosion in channels is through the construction of check dams, which allow control of the rate of water flow.

Overland surface flow is highly erosive to unprotected graded and/or topsoiled slopes and can result in the production of sediment. It may be controlled by creation of surface depressions and roughness, and by breaking up long slope lengths. A number of methods can accomplish this. First, diversion dikes (made of compacted soil) can be constructed parallel to surface contours (fig. 12). Second, diversion swales (ditches) or diversion channels (ditches combined with adjacent parallel dikes placed on the downslope side of the ditches) can also be used. These diversions are constructed along the site perimeter, both above a slope to protect the surface from offsite runoff, and below it to intercept and channel sediment-bearing runoff to settling basins. Horizontal microdepressions and surface roughness, which will decrease water flow velocity, may easily be produced on moderate slopes by "walking" a caterpillar tractor up and down the slope. This treatment also serves to compact the surface. As soon as possible after completing the grading phase of an operation, mulch should be applied and vegetation planted. Adequate vegetative cover provides one of the best long-term methods of reducing surface erosion. Mulch and vegetation serve to increase surface roughness, reduce the impact of rainfall, and increase the water storage capacity of the soil.

HOW CAN THE PRODUCTION OF SEDIMENT BE CONTROLLED?

Sediment generated by the reclaimed site may be trapped by the construction of ponds or basins. Sediment traps function by reducing the rate of water flow, which provides time for settling of suspended solids. In mountainous areas, the size of sediment traps may be restricted; therefore, it is a common practice to construct a series of basins along a water course. Generally, these chains of sediment traps are more effective than a single large pond of equivalent volume. Spillways or perforated risers (vertical pipes with perforations to allow low-velocity drainage from

the pond) may be used as water outlets from sediment traps. These traps can also be installed within water channels in the form of barriers constructed with different materials including sandbags, gabions, and logs. Any raised barrier within a channel will serve to reduce water velocity and enhance the settling of suspended particles. In addition, spillways over sediment traps should be constructed in such a manner that the discharge does not produce erosion. Finally, sediment traps require maintenance in the form of occasional removal of accumulated sediment. Generally, this is done when the trap is half full. The removed sediment must be disposed of in a manner that will not result in further erosion. If the sediment does not contain toxic materials, it may be used as topsoil.

HOW SHOULD TAILINGS PONDS BE TREATED?

As previously discussed, tailings ponds in the West are frequently impounded behind dams. In many cases, ponds at older orphaned mine sites may be structurally weak due to poor design and erosion. Because these dams still function to contain tailings, it is recommended that they be strengthened as part of the reclamation project, and that care be taken not to rupture them in the process. If the dam of a pond in a nonarid location is intact, it is likely that the pond will contain subsurface water, even if none is present above ground. For this reason, a pond will require at least partial dewatering before treatment of the surface with heavy equipment. It is recommended that ponds be permanently dewatered to a level well below the root zone of planned vegetative cover. This is necessary to prevent subsurface pond water from transporting toxic materials into the root zone. It is likely that the water in a tailings pond contains high concentrations of mineral salts and, in the case of acidic waste, has a low pH.

HOW CAN SMALL TAILINGS PONDS (UP TO 4 HA, OR 10 ACRES) BE DEWATERED?

Because tailings ponds are of diverse designs, they may require one or more possible treatments to be effectively dewatered. Usually, this is accomplished by digging one or more ditches into the sediment, then pumping or siphoning the water. An alternative method of drainage is provided by horizontal or vertical wells, but vertical wells require mechanical pumping. By whatever means the dewatering is accomplished, the water will probably require treatment before it can be released into the watershed, because it is likely to contain high concentrations of soluble salts and other chemicals. Therefore, it is important that tailings pond water be analyzed prior to draining. If the chief treatment of the water is to be pH adjusted, the water can be run through filter ponds or tanks containing lime or gypsum. As previously mentioned, pond dewatering should be done as much as a year in advance of further treatment to allow sufficient surface stabilization for the operation of heavy equipment.

Permanent dewatering of the root zone is accomplished by placing drainage pipes in the dam, or around its edges, at an appropriate level, then recontouring the pond surface with earth fill (perhaps obtained from a nearby waste dump), to give it a convex shape. If any portion of a dam is removed, it should be done only after dewatering. The purpose of the domed shape of the pond surface is to reduce the collection and infiltration of surface water into the pond. The new surface is then treated and topsoil is added. Also, the pond can be protected from offsite water by the appropriate placement of adequate diversion channels. Because many ponds are located in the bottoms of canyons and ravines, diversion channels should be of sufficient size and construction to handle runoff from intense storms without erosion of channel walls. Adequate systems can be designed by hydrologists and engineers, who first analyze the potential runoff magnitude.

Probably, the best way to strengthen a tailings pond dam is to reenforce it from the front with earth fill. This operation can be combined with the recontouring of a site, effectively burying the dam (fig. 6).

HOW CAN LATERAL MOVEMENT OF OFFSITE UNDERGROUND WATER THROUGH WASTE MATERIALS BE CONTROLLED?

The problem of controlling lateral underground water movement from off the treatment site through waste materials is a difficult one. This situation was encountered at the Sheldon Mine. The gravity of the problem is compounded by the fact that such flow may be at a depth well below that at which chemical neutralization of the wastes is possible. Restriction of this lateral water movement through a waste dump or tailings pond depends upon certain conditions such as subsurface geological conditions and the source of water. In some circumstances, the water source may be blocked by sinking a retaining wall into the lower limit of the aquifer where, in other situations, it may be possible to divert the water flow using horizontal wells.

A related problem concerns the drainage of ground water from underground lateral workings. A common way to treat this situation is to seal the offending working by drilling vertical holes into it at intervals, then plugging it with concrete or "bentonite." Sometimes, the source of water is a vertical shaft, which passes through water-bearing strata. In this case, it may be possible to plug the vertical shaft. The control of drainage from underground mines is detailed in the EPA publication on inactive and abandoned underground mines which is listed in the Bibliography.

Chemical Treatment of Abandoned Mine Tailings

WHAT CHEMICAL CONDITIONS MAY BE FOUND AT THE SURFACE OF ABANDONED MINE SITES?

Generally, the chemical nature of waste materials is unique for each mining site, depending on local surface and subsurface composition, the nature of the ores that were mined at the site, and any extraction procedures that might have been carried out during the operation of the mine. The tailings of some mines may have been reworked at more than one period in history, each time altering and restratifying the chemical composition of the surface waste materials. It is important to note that the physical and/or chemical soil structures and chemical compositions of waste dumps and tailings ponds are not homogeneous. Core samples taken at various locations on the surface of a waste dump or tailings pond can indicate considerable variation in chemical composition with respect to depth and horizontal postion, reflecting the operational history of the mine. For this reason, it is possible that different treatments will be required for different zones in a single waste dump or tailings pond.

There are two major classes of soil chemical conditions that may cause ecological problems at a site: excess alkalinity or acidity; and, the presence of heavy metal salts or other toxic chemicals. Many plants are highly sensitive to soil pH conditions that deviate from 7 (neutral). For example, acidic soils have a pH value lower than 7, while alkaline soils have pH levels above 7. While plants differ with respect to their "preference" for pH, most will grow well in the range between pH 6 and 8. A few will tolerate conditions of greater alkalinity or acidity.

Two main objectives in treating chemical conditions in orphaned mine wastes are attempting to neutralize pH extremes and detoxifying poisonous salts and metals occurring near the surface of the wastes that could contaminate the topsoil; and preventing percolation of large quantities of surface water through the waste materials that will leach chemicals from the tailings and contaminate underground or downstream surface waters. For the first objective, soil pH can be adjusted through the addition of amendments. For instance, lime will act to neutralize acid conditions, while alkaline soils can be treated with gypsum. Poisonous salts and metals, however, must be treated by specific methods. In both situations, efforts are made to physically separate the topsoil layer from the toxic waste materials. The second objective, reduction of water percolation through the tailings, is approached through a combination of physical manipulation of the site and its surface, addition of soil amendments, and planting of vegetative cover. Another component to the problem of

water supply contamination which, in many instances, is very difficult and/or expensive to treat, is the lateral flow of underground water from offsite sources through the waste material. This problem is briefly discussed in the section on the physical treatment of mining wastes.

Treatment of Acidic Wastes

Acidic wastes and drainage from them can be highly detrimental to the ecology of a watershed. Terrestial plant life is adversely affected and the balance of aquatic ecosystems can be disrupted to the extent of making water in lakes and streams uninhabitable for fish and water-dwelling plants. Acidic wastes are usually treated with lime, but, in some areas, it may be possible to regrade the site with alkaline topsoil, if it is available. The technique of alkaline regrading is discussed in the EPA book on inactive and abandoned underground mines, which is listed in the Bibliography.

WHAT FORMS OF LIME CAN BE USED FOR TREATING ACIDIC MINE WASTES?

In agricultural practice, lime is used to neutralize highly acidic soils to increase their suitability for plant growth. Lime is invaluable for treating soils in regions receiving large amounts of rainfall, where water has leached basic salts from the soil, leaving acidic residues behind. The addition of lime affects the soil physically, chemically, and biologically. This is because lime encourages a granular soil structure and stimulates organic decomposition and the production of humus. These effects combine to encourage the growth of legumes and other deep-rooted plants.

Lime comes in several forms that differ in strength and stability. It is important to know something of the differences between the three major forms of lime, because they must be used and handled in different ways to be properly effective. For agricultural use, lime is manufactured from a number of sources, including pulverized or ground limestone, oyster shells, or certain industrial byproducts. The following are different types of lime and how they are produced. Lime oxide is often called quicklime or burned lime, because it is manufactured by heating limestone in kilns. Slaked lime is sometimes erroneously called hydrate. It is produced by adding water to burned lime. Both quicklime and slaked lime are kept in bags to maintain their purity, because they can absorb water from the air. Also slaked lime can take up carbon dioxide from the air and thereby lose its strength. Carbonate of lime is simple ground or pulverized limestone, oyster shell, or bog lime. It is also obtained from other sources. Calcite (calcium carbonate) and dolomite (calcium magnesium carbonate, sometimes called dolomitic limestone) are two additional forms of lime carbonate. Quicklime is more caustic than other forms, so it should be handled carefully.

Ground limestone (carbonate of lime) is effective in increasing crop yields (Brady 1974), and is the most popular form of lime for this purpose. However, a more concentrated form may be preferable for treatment of highly acidic mine waste materials. The chemical purity, strength, and stability of lime varies with the type, physical constituency, and method of manufacture. It is important to note that lime changes chemically once it is added to the soil, possibly affecting its treatment effectiveness. Lime oxides are commercially guaranteed on the basis of their neutralizing power, calcium oxide content, or the relative percentages of calcium and magnesium. Ground limestone is usually guaranteed according to carbonate content or its neutralizing power. The interpretation of lime potency is somewhat complex, so the reader is referred to the text by Brady (1974) listed in the Appendix for further information. As a rule of thumb, however, 1.0 ton of finely ground limestone is roughly equivalent in neutralizing power to 0.7 ton of slaked lime and 0.5 ton of quicklime.

WHEN SHOULD LIME BE USED AND WHAT TYPE SHOULD BE SELECTED?

Deciding whether or not to use lime on a site largely depends on the soil acidity of pH. First, the pH of both surface and subsurface

samples is determined. If the pH is 6 or less, the application of lime is recommended. Once a decision is made to use lime, the choice of the type of lime is generally based on five factors:

1. Chemical guarantee of the limes available,
2. The cost per ton of applied lime,
3. The rate that the lime reacts with the soil,
4. The constituency of fineness of the lime,
5. Costs of storage, handling, etc.

For a detailed discussion of these points see Brady (1974).

HOW IS THE PROPER AMOUNT OF LIME DETERMINED?

The amount of lime that is required to reduce the pH of waste materials near the surface depends on a combination of factors including the surface and subsurface pH; texture, structure, and organic content of the material to be treated; the kind and fineness of the lime; the pH requirements of the vegetation to be planted; and various cost factors (Brady 1974).

Highly acidic mine wastes require much higher concentrations of lime than agricultural soils. It is recommended that soil samples from mine waste materials be analyzed in a soil chemistry laboratory and tested to ascertain the amount and type of lime required to raise the pH to the desired level. Because waste dumps and tailings ponds are not homogeneous throughout, it is desirable to take a number of samples for pH and chemical content determination, carefully noting the surface location and depth of the sample.

Overliming (application of too much lime) raises the soil pH beyond the optimal point for plant growth. Also, it can lower the ability of plants to take up minerals. As plant species differ with respect to soil pH tolerance, the defined point of overliming varies. The danger of overliming, however, is greatest in sandy soils, which are low in organic content and have less capacity to "buffer" or accommodate the strength of the lime than heavier soils. In addition, it should be noted that certain plants, such as blueberry, laurel, and rhododendron, require acidic soils, because their growth is retarded by the use of lime.

BY WHAT METHODS CAN LIME BE APPLIED TO MINE WASTES?

To obtain rapid neutralization of the soil, the lime should be applied to land that is plowed. Then the lime is worked into the soil during preparation for planting. Alternatively, the lime may be applied to the surface, then plowed under, but this method is slower acting. The long-range effects, however, are equivalent to those produced by the first method, and it has the advantage of permitting bulk spreading of the lime. In agricultural practice, lime application is sometimes incorporated into the seeding process, but the higher lime concentrations that may be required for neutralizing mine wastes could be harmful to the seeds. The season in which lime is applied is not important, but sequence in treatment is. Hydrated lime requires time to work into the soil, so it should be applied well in advance of planting, while ground lime can be applied 24 hours before planting. If lime is to be plowed into the waste materials, the root depth of the plants that will be used for revegetation must be considered.

Also, lands to be reclaimed following mining operations differ from agricultural lands in that the problem to be treated extends far below the soil surface, and the acidic content of the wastes is much greater. Therefore, greater quantities of lime are required for treatment, and simple topical application of the lime may not produce the necessary effect. Because the pH may vary at different sites on the tailings surface, it is important to consider differential treatments with respect to the strength and quantity of lime required. If regrading of the waste material is part of the treatment, it may be worthwhile to consider combining the lime application with the regrading process. This extends the lime treatment to a greater depth. Alternatively, holes may be dug or drilled into the surface at regular intervals and filled with lime. This method allows gradual lateral distribution of the neutralizing effect of the lime over a period of time (fig. 7). Other methods of effecting subsurface soil treatments may suggest themselves in the course of a project.

Finally, soil pH monitoring should be integrated into the overall postreclamation project management program. Supplemental lime treatments by one of the suggested methods may be necessary, if lateral or vertical subsurface water movements carry acidic materials into the surface soil.

Treatment of Alkaline Wastes

In regions of the Western United States where rainfall is limited, alkaline soil conditions often predominate and are sometimes associated with mine wastes. In general, drainage from alkaline mines or waste materials is not as environmentally harmful as that from acidic wastes and mines. An alternative to treatment of mildly alkaline wastes is to plant them with salt-tolerant vegetation.

HOW CAN SOIL ALKALINITY BE TREATED?

Treating alkaline or saline soils may be approached in three ways: eradication of the salts; conversion of the salts to less harmful forms; and control of salinity through a management program. In agricultural situations, the most common treatment is eradication of the salts by underdraining the soil, or applying excess water to flush or leach the salts from the soil. Conversion involves changing insoluble salts to soluble forms through the addition of chemicals, such as gypsum, then leaching the soluble salts out of the soil. Control programs are aimed at reducing evaporation to retard upward movement of salts through the soil into the root zone. Because this approach tends to be expensive, other alternatives are often used including programs of frequent irrigation to dilute salinity during critical periods of plant development or using salt-resistant varieties of plants. When treating abandoned mine wastes, conversion utilizing gypsum is probably the most effective and economical of the three approaches in dealing with soil alkalinity.

Gypsum is a sulfur-containing salt (hydrated sulfate of calcium). It chemically reacts with insoluble alkaline carbonates, converting them into soluble alkaline sulfates, which may then be leached from the soil. Generally, several tons of gypsum are applied per hectare (acre). It should be cultivated into the soil, rather than plowed under. Because water is necessary for the chemical reaction to take place, the treated soil should be kept moist. After a period of time, the treatment is followed by thorough irrigation to leach some of the soluble alkaline salts from the soil. Please note that using gypsum without adequate water treatment may be hazardous.

It is also possible to treat alkaline soils containing sodium carbonate with sulfur. Sulfuric acid is produced and acts to both neutralize the alkalinity of the soil and produce sodium sulfate, a neutral salt that is relatively harmless in the soil.

Topsoiling

Usually, abandoned mine-waste materials are so sterile or highly toxic that they cannot support plant life, even after they are treated on the surface. In order to provide a suitable substrate for the restoration of plant life, it is necessary to cover these wastes with a layer of topsoil taken from another location. Unlike modern stripmining operations that are required to remove and set aside topsoil before removal of the overburden, abandoned mine wastes have been dumped on the topsoil, making its replacement necessary.

WHAT SHOULD BE CONSIDERED IN THE LOCATION AND SELECTION OF TOPSOIL?

Generally, selection of a source of topsoil is made on the basis of its properties and availability. Locating a source of good quality topsoil can become a problem. In some situations, procurement of high-quality topsoil requires considerable political expertise and negotiation, because the topsoil is permanently "borrowed" from the donor site. This site may require reclamation treatment after the topsoil is removed. In some areas, environmental regulations prohibit such borrowing. Further, the distance that topsoil must be hauled directly increases the cost of

the project. Too much compromise with respect to topsoil quality can adversely affect the success of the entire reclamation project.

When selecting topsoil, the best rule of thumb to follow is that it should closely approximate that on undisturbed land surrounding the reclamation site. Topsoil should be selected for its texture, available water holding capacity, organic content, workability, spreadability, and tilth. It is important to have topsoil tested in a soil chemistry lab for suitability before it is borrowed. In general, loam is preferable to alluvial material with high sand and/or gravel content. Less desirable are silty soils, which tend to crust. Rocks may be desirable, however, because they can be worked into the surface, serving both to anchor the soil and provide small surface disturbances fostering vegetative growth. Finally, the quality of topsoil may deteriorate if it is stockpiled for periods exceeding 3 months.

HOW DOES MULCH FUNCTION AND WHAT TYPES ARE AVAILABLE?

The surface of the reclaimed mine site must be able to absorb and hold sufficient moisture for sustained vegetative growth. Too much water, however, will leach toxic salts from the waste materials into the underground water table.

Applying mulch before, along with, or following the seeding operation accomplishes several purposes. One of the most important is its function of reducing soil detachment and erosion by precipitation and wind, thereby creating a stable environment for germination and growth of the new vegetation. Also, mulch provides insulation against excessive heat or cold, increases organic matter in the soil through decomposition, helps retain moisture in the soil, and affects soil surface microclimate and nutrients available to the germinating seedlings. Finally, mulch is used to control soil temperature, because the addition of dark-colored mulch increases absorption of heat from the sun and warms the soil, while light-colored mulch reflects heat and serves to protect the soil from overheating.

Several types of mulch are available including straw, wood, or paper fiber mixed with asphalt emulsion and water (hydromulch). Cement and other commercial binders are also used. Plastic emulsions are marketed, but these are recommended more for soil stabilization when revegetation is not a goal, because they form a sturdy crust, which seedlings have difficulty breaking. Other fibers such as ground newsprint, rice hulls, and cubed alfalfa have been used, but are not as satisfactory as wood fiber. Wood fiber stays in place for periods of up to a year, even in areas with high slopes, and has been shown to be effective in reducing germination time and increasing seedling survival rates. Also, straw is highly effective, if it is suitably tacked to the surface or crimped. Additional information on mulching may be found in the EPA reference on erosion and sediment control listed in the Bibliography.

Fertilizing

WHAT CRITERIA SHOULD BE APPLIED TO THE SELECTION OF FERTILIZERS?

Generally, fertilizers are selected on the basis of laboratory soil analysis. This analysis determines which nutrients are totally lacking from the topsoil in which the plants are to be placed, and which nutrients need to be augmented. Usually, a soil lab is prepared to recommend which fertilizers will be best suited for the site conditions and plant species to be used. Also, the lab makes recommendations on the amounts of fertilizer to apply. For further information, see the EPA reference on erosion and sediment control listed in the Bibliography.

Revegetation

Compared to the eastern portion of the United States, revegetation of mined lands in the West is difficult, because three-quarters of this land receives less than 51 cm (20 inches) of precipitation annually, and is subject to comparatively great diurnal and seasonal temperature extremes. In those areas receiving snow after the ground has frozen, much of the precipitation runs off. Also, in regions of low humidity, snow sublimes (is converted directly to water vapor)

and again, the moisture is not taken up by the soil. Therefore, in many areas in the West, revegetation efforts must use species that can survive with little moisture. Special efforts must also be made to assist the plants in becoming established. Generally, it is best to use species that are native to the region and adapted to local conditions.

The first objective of site revegetation is to provide soil stabilization as rapidly as possible. This is best accomplished by first mulching, then planting a mixture of rapid-growing grass species combined with legumes that will offset the nitrogen deficiency common to most mine-waste materials. Once the regraded waste surface is initially stabilized, additional planting is done, working toward creating a long-term vegetative cover.

An important general consideration in revegetating all sites is that seeds, sprouts, and seedlings (as well as adult vegetation) must be protected from animal and human damage. Grazing animals can be particularly detrimental.

SHOULD SUCCESSIONAL OR CLIMAX PLANTING BE USED IN WASTE MATERIAL-REVEGETATION?

Three major alternatives may be followed with respect to reclamation-site revegetation with native plant species: successional planting; climax planting; or a combination of the two. Climax planting refers to initial planting of the reclaimed area with identical or similar species to those growing on undisturbed land immediately surrounding the treatment site. The term successional planting describes the practice of first planting species that easily become established, then preparing the site for the gradual introduction of climax vegetation through various actions including developing improved soil conditions and ground cover. Conditions on the treated site may not support climax planting without extensive preparation, particularly if the local climax growth consists of deep-rooted trees. Further, there are two reasons to question whether climax planting will ever attain its ultimate goal. First, waste materials that underlie the topsoil on the treated site are significantly different from the subsoil conditions that exist off the site, so it is probable that surface soil will not develop on the treatment site in the same manner as off the site. Second, the term vegetational "climax" does not necessarily refer to a permanent condition. The ecological conditions that control climax growth gradually change with time, and the local climax type may change. Therefore, one cannot predict with certainty that the growth on the reclaimed site will ever "catch up" with the surrounding vegetation. In arid regions of the West, native plant species and communities are characterized by slow growth and development.

The third alternative, which is recommended for the revegetation of abandoned mine wastes, is to devise a planting program that combines aspects of both climax and successional planting by initially stabilizing the site with rapid growing cover species and then artificially preparing localized sites for climax species. The first objective is accomplished by planting a mixture of rapidly growing grasses and, perhaps, shrubs such as mustard. In arid or semiarid areas, these plants require assistance in the form of irrigation. Later, this initial growth can be augmented by planting larger shrubs and/or trees in specially prepared sites that offer soil of sufficient quality and depth to promote and protect the deeper root growth from the toxicity of the underlying waste materials.

WHAT CRITERIA SHOULD BE USED IN SPECIES SELECTION?

Plant species for the revegetation of abandoned mine sites should be selected by several criteria. The most important of these is potential for survival in the local climate. All other variables, including soil conditions, can be at least partially controlled. In general, locally occurring vegetation is better adapted to an area than introduced species. In the arid and semiarid regions of the West, growing conditions vary considerably with altitude, slope aspect, and temperature. A variety of conditions can exist within a small radius.

The next most important criterion is the suitability of the selected plants to the soil conditions that are created on the surface of the mine wastes. Soil pH and salinity are both im-

portant factors to take into account; however, many species exist that are relatively tolerant of extremes of soil pH and salinity.

In addition, rapid growth rate and soil conditioning capabilities are important factors in species selection. For instance, legumes are important, because they provide nitrogen, which is deficient in mine waste materials. Also, they have tap roots and can incorporate organic material into the soil at the greater depth, than do grasses. In addition, some species of shrubs produce a high amount of litter, which increases the organic content of the soil. Another important consideration is the interactive effects between plants. The dead foliage of some species secretes materials that are toxic to other plants, discouraging growth beneath them.

Most of the additional criteria for species selection is function related, such as potential for soil conditioning, soil stabilization (the root systems of grasses have excellent soil-holding capabilities), forage, shade, and esthetic quality. In some areas, there may be legal restrictions on certain species. For example, in Arizona, it is illegal to plant morning glories, because they are deemed a threat to cotton crops. Probably, the best source of specific information on optimal species for the conditions at a given site is a botanist or plant physiologist at a local university, who can make a determination based on an analysis of the site conditions, combined with a knowledge of regional species. Also, soil conservation technicians may provide information, if there is a local Soil and Water Conservation district office. There is abundant literature on the revegetation of mine wastes, but much of it is based on experience in the eastern portion of the nation where conditions and predominant plant species are significantly different from those in the West. The reference by Doyle, listed in the Bibliography, discusses the problem of revegetation of mined land in the arid and semiarid regions of the West.

In regions receiving little rainfall, it may also be desirable to plant different species of vegetation on north- and south-facing slopes. This pattern can be observed in natural vegetation, and is predominantly due to differences in soil moisture resulting from exposure to the sun. If this pattern is followed in revegetation of an area where it would naturally occur, the long-term chances for survival of the new growth may be improved.

WHAT METHODS OF SEEDING AND PLANTING CAN BE USED FOR REVEGETATING MINE WASTES?

Seeding techniques

In most instances, seeding methods commonly used in revegetating stripmine tailings may be used on abandoned underground mine sites. These might include hydroseeding, broadcasting by use of blowers or cyclone seeders, and hand seeding. The chances of successful germination will be increased if the surface is not disturbed after planting. Natural seeding, such as leaving revegetation of a site to nature, probably will not result in rapid site stabilization. Seeding techniques are discussed in a number of books on mine reclamation, including Thames (1977), listed in the Bibliography.

A number of factors affect seed germination. Soil moisture and temperature are two of the most important. Seeds that are soaked overnight in water before planting germinate more quickly than seeds that are dry immediately prior to spreading. A common practice is to spread seeds with mulch. Please note that optimal soil temperatures, as well as temperature tolerance limits of seeds, vary with different species. Generally, germination and growth is faster if daytime temperatures are warm; however, soil temperatures over 38° C (100° F) can be detrimental to some species. The temperature of the soil surface can be controlled by its color. For example, dark soils can become very hot. This can be compensated for by utilization of a light-colored mulch. Alternatively, cold soils can be warmed with dark-colored mulch.

Planting techniques

Usually, direct seeding of trees and shrubs is not effective under the arid conditions prevailing in many areas of the Western United States. They must be transplanted at advanced stages of development, or planted in the seedling stage. If trees are to be planted and the topsoil cover over the waste material is shallow, pits at a depth and

diameter up to 1.2 m (4 feet) must be excavated into the waste material, lined with a protective layer of lime (for acid tailings), then filled in with a mixture of topsoil, mulch, and fertilizer. A variety of seedling containers are available in which the seedlings may be directly planted.

Trees and shrubs may be planted in semiarid regions in condensation traps. These are constructed by covering the basin in which a seedling is planted with a plastic sheet. The sheet is sealed around the perimeter of the basin with soil cover and rocks, while the plant projects through a hole in the center. Rocks are then placed on the plastic sheet around the plant to weight the plastic down into a funnel shape. Evaporating soil moisture is condensed on the sheet, then it runs toward the center and drip irrigates the plant. This structure also functions to collect rainwater that falls near the seedling. More information about these devices can be found in the water harvesting reference by Aldon and Springfield (1974), listed in the Bibliography.

Additional methods of planting in arid regions include using tubelings and supplemental root transplants. Tubelings are nursery seedlings that have been grown in 2-ply paper tubes approximately 6.4 cm (2.5 inches) in diameter. When the tubelings reach a certain size, they can be planted (still in the tube) in auger-drilled holes. After planting, the tubes are sealed around the top, then the plants are allowed to develop without further attention. A variety of plantable seedling containers are now available. Supplemental root transplants involve planting two connected rhizomatous shrubs in a single hole. The top of one of the plants is removed and its root system is planted in deep moist soil, while the other plant is placed normally in drier soil near the surface. Then the plant with the foliage draws moisture through the rhizome from the root system of the deeper plant. These methods are discussed in the book by Doyle (1976), listed in the Bibliography.

It has been found that many plant species have symbiotic associations with microscopic fungi. The fungi assist the plant roots in the uptake of water and certain nutrients. Research indicates that certain species of shrubs, which occur in the West, demonstrate improved growth in soil that has been innoculated with mycorrhizae. Species benefiting from such an association may have an advantage in becoming established on reclaimed mine wastes in areas where moisture is limited. Readers interested in more information regarding this subject are referred to an article by Aldon and Springfield in the book by Thames (1977), listed in the Bibliography.

Irrigation

IS IRRIGATION OF REVEGETATED MINE SITES NECESSARY?

Depending on site conditions, species selection, and planting methods, irrigation may be necessary for the first year or so, until plants become established and can survive under natural moisture conditions. One major reason for recommending native vegetation species for revegetation is to avoid the need of prolonged irrigation. In many arid or semiarid areas, however, temporary assistance in the form of irrigation may be required. Alternatives to irrigation, such as special planting techniques, are discussed in the section on planting methods.

Of the various forms of irrigation available, drip irrigation is probably one of the best adapted, due to its potential for water economy in remote arid sites; however, it provides highly localized coverage and is not suited to the establishment of grass cover. In the latter case, periodic sprinkling is probably the method of choice. Whatever the method used, the system should be designed for the task and carefully maintained. Various aspects of irrigation are discussed in an article by DeRemer and Bach in the book by Thames (1977), listed in the Bibliography.

Chapter Five

POSTTREATMENT MONITORING AND MANAGEMENT

The ultimate goal of a reclamation project on an orphaned mine site is to achieve a state of ecological and esthetic equilibrium and harmony with the surrounding landscape. In this state, the site will be ideally stable and maintenance free with respect to various conditions including erosion and vegetation. Since soil stability is, in most cases, dependent on the successful establishment and maturation of permanent vegetative cover, stabilization may require several years to achieve. In the period that intervenes between site treatment and the development of a state of self-maintaining stability, a program of monitoring and management is ususally necessary. The monitoring program should include land located both above and below the site in the watershed.

WHAT PROVISION CAN BE MADE FOR CONTINUED SITE MAINTENANCE IN THE EVENT OF A CHANGE IN LAND OWNERSHIP?

Because some sites may require considerable time to achieve a state of equilibrium, provision for continued site protection and maintenance in the event of a change in land ownership may be necessary. The circumstances surrounding the initiation of a site reclamation program can vary considerably depending on land ownership and the nature of the problems presented by the untreated site. Generally, an agreement for continued maintenance can be incorporated into a deed covenant. In most instances, it is advisible to obtain the assistance of an attorney in this matter.

WHAT SHOULD BE INCLUDED IN A POSTTREATMENT SITE MONITORING AND MAINTENANCE PROGRAM?

Erosion control

The site should be inspected periodically and after heavy storms for signs of surface water erosion and/or damage to erosion control structures. In addition, water handling structures should be inspected for breaks, damage to walls, and collection of sediment and vegetative debris. If found, damage must be repaired and sediments removed. Also, sediment trapping devices require cleaning, when approximately half filled. Depending on its quality, sediment should be disposed of in such a way that it will not erode again, or it might be used for supplemental topsoil. In addition, site access roads must be inspected and maintained. If wind erosion is a problem, the site may need to be sprayed with water or other stabilizing materials, until stability can be achieved with vegetation.

Vegetative cover

Vegetation can be monitored by visual inspection, along with a program of making periodic photographic records. Photographs are most effective for this purpose if regularly taken from established points for comparison. If growth of the vegetation is lagging, soil moisture and quality analysis is advisable If required, irrigation should be adjusted and/or supplemental fertilizer applied. In addition, particular attention should be paid to soil pH. If changes in pH are found, they require immediate correction by additional soil amendment treatments, before the soil becomes toxic to vegetation. Generally, subsurface treatment (amendment filled, regularly spaced auger holes) will be more effective in the long run, than surface application methods.

If the planted vegetation does not take hold within a reasonable period of time, a soil analysis should be performed. If soil quality is good and if sufficient water has been applied, the suitability of the planted species for the environment on the site should be considered. Re-

planting with alternative species may be indicated.

Water quality

Ground and stream water quality must be regularly monitored. Stream water samples should be taken at points located immediately upstream and downstream from the site and compared. It is a good idea to take samples at several points downstream to detect possible underground flow into the stream.

Water quality may not improve immediately after treatment of a site that had been producing problems, but continued lack of improvement over a period of several months may indicate that the treatment is not sufficient. In this case, possible existence of additional untreated sources of polluted water from the site (such as drainage from unblocked lateral workings) should be considered. Another possibility, particularly in the case of tailings ponds constructed in canyons and ravines, is the existence of underground water flow from the surrounding canyon walls passing through the tailings material and into the downstream surface or underground water supplies.

GLOSSARY OF SELECTED TERMS

Angle of repose: The maximum steepness of slope at which a pile of material, such as sand, dirt, or mine waste material, will remain stable without sliding.

Loam: A soil containing a moderate amount of sand, silt, and clay. Generally, loam soils contain less than 52 percent sand, between 28 and 50 percent silt, and from 7 to 27 percent clay.

Mulch: A layer of organic material derived from the residue of plants or inorganic material that is applied to the topsoil surface to create a more favorable environment for the establishment of vegetative growth.

Spoil: Non-ore material that overlies a mineral deposit and must be removed in surface mining to gain access to the ore. This term does not properly apply to the waste materials of underground mines.

Tailings: Debris or unused ore material remaining after the available minerals are removed from the ore by treatment.

Tilth: The physical condition of the soil with respect to plant growth. Soil "tilth" refers (among other things) to its stability, granulation, moisture content, capillary water holding capacity, rate of water infiltration, drainage, and degree of aeration.

Appendix

ADDITIONAL COMMENTS ON THE NATURE OF TAILINGS PONDS AND WASTE DUMPS

In most instances, mine wastes and/or tailings are the focal point of reclamation efforts on abandoned mine sites. An understanding of their structure and content is valuable to reclamation project planners and workers. More detailed information on this subject is found in several of the references listed under Mining Information in the Bibliography.

Tailings in many of the older ponds at mines that have seen periodic activity over a number of years may be stratified with the older materials at deeper levels, reflecting the operational history of the mine. Processing techniques for many minerals have significantly improved over the years, greatly increasing extraction efficiency. Milling methods of a century ago produced tailings having the consistency of sand. Today, the particle size of tailings approaches the fineness of talcum powder. A modern process, differential flotation, permits recovery of minerals that were formerly discarded in tailings and other wastes. For example, in copper mining, it is now possible to economically separate molybdenum, gold, and silver. Previously, these were passed on to the tailings pond. Depending on the type of mine, processing chemicals may have also changed, resulting in stratification of pond chemical content. In many instances where the mineral content of older tailings and wastes was sufficiently high, the ponds and dumps have been reworked, perhaps more than once as technologies continued to improve. Depending on the methods and thoroughness of reworking operations, the pattern of vertical stratification of wastes may have been completely or partially disrupted. Important to reclamation efforts is the fact that such alteration may mean that the nature and concentrations of toxic materials in a given dump or tailings pond may differ from one location to another. This can materially affect the nature and/or intensity of treatment necessary for revegetation of the pond or dump surface, because various portions of a pond's surface may require different treatments.

Some abandoned mines may not have large waste dumps. The mining process of block caving, where ore is removed from beneath through a side tunnel, results in caving in of the surface material overlying the ore deposit. This material would have otherwise been placed on a waste dump. However, such mines can produce large tailings ponds.

The chemical content of tailings depends on the minerals mined and extraction methods used. Some processing chemicals are extremely toxic. For example, a technique employing cyanide compounds had been used in some gold operations. The chemicals in the pond may undergo further reaction over long periods of time, thus changing their character. It is recommended that safety information specific to the particular materials mined and processed at a site be consulted in the planning stages of a reclamation project.

In addition, the overall structure of dumps and tailings ponds largely depends on the terrain of their location and the proximity of water. Also, the dams of old tailings ponds may not be structurally sound. Frequently, small dams were constructed across side canyons, and as the ponds filled, the dams were extended in stages. In some cases, these dams may have been poorly engineered. Structural reinforcement of such dams prior to reclamation should be considered, because dam failure is a possibility. Abandoned dumps with *no water retained* tend to become stronger as they dry.

In arid regions, tailings ponds may be completely dry, but where a pond still contains surface or subsurface water, the consistency of the tailings may pose potential problems. In some ponds, the tailings may be suspended in a gelatinous or colloidal state or be present as a fine mud. Such ponds may be potentially hazardous until they have been adequately dewatered.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.